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DEVELOPMENT STUDY OF THE X-RAY SCATTERING PROPERTIES
OF A GROUP OF OPTICALLY POLISHED FLAT SAMPLES

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16. Abstract Four optically polished flat samples selected from twelve samples tested in Phase I of this contract were tested at wavelengths of 8.34 Å, 13.3 Å, and 44 Å and 0.5°, 0.92°, 1.5°, 2.0° and 4.0° angle of incidence. The four samples were also tested at 8.34 Å and 0.92° angle of incidence for three additional angular orientations about an axis normal to the sample surface: 45°, 90° and 180° from the 0° (Phase I) position. The tests indicate that the scattering was greater at 44 Å than at 13.3 Å and 8.34 Å. The orientation tests indicated that no great irregularities are present as the results were comparable for all samples tested.					
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PREFACE

The objective of Phase II of this program was to study the x-ray scattering of four optically polished flat samples selected from twelve samples tested in Phase I of this program. These four samples were tested at 8.34 Å, 13.3 Å, and 44 Å and 0.5°, 0.92°, 1.5°, 2.0°, and 4.0° angle of incidence. The four select samples were also tested at 8.34 Å and 0.92° angle of incidence for three additional angular orientations about an axis normal to the sample surface: 45°, 90°, and 180° from the 0° (Phase I) position. The tests indicate that the scattering was greater at 44 Å than at 13.3 Å or 8.34 Å. The orientation tests indicated that no great irregularities are present as the results were comparable for all samples tested.

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INTRODUCTION

It has been shown ¹⁻⁴ that the limiting factor in the performance of x-ray telescopes is the scattering of soft x-rays by the optical surfaces.

One important point learned in previous tests of soft x-ray telescopes is that visible light tests do not predict the performance in the soft x-ray spectral region. The manufacturing techniques used were not sufficiently controlled to produce a telescope giving predictable performance. For future x-ray astronomy missions such as the HEAO, it is important to choose the optimum materials and manufacturing techniques to provide higher quality, lower cost telescopes. A previous study ⁵ had made some of the required measurements and answered some questions regarding materials, but it also produced some questions which can only be answered by continued research into the problem.

The first phase of this program ⁶ involved measuring the properties of an x-ray beam reflected by twelve optically polished flat samples at one wavelength, at one angle of incidence, and at one orientation about an axis normal to the sample surface.

The four (4) Phase II samples were selected from the twelve (12) Phase I samples on the basis of the results of the scattering measurements plus other factors, such as ease of fabrication and durability. Each of the four samples was tested at three wave-

lengths, at five angles of incidence, and at three angular orientations about an axis normal to the sample surface. In order to obtain data which are suitable for application to grazing incidence mirror construction, it is necessary to use a measurement system having an angular resolution of one arc second which is the order of the telescope resolution.

EXPERIMENTAL PROGRAM

During Phase II of this program, the scattering of x-rays by optically polished flats was measured for four (4) select samples. Each of the four samples was tested at each of the conditions shown in the tabulation below to determine the effect of wavelength and angle of incidence on the scattering properties:

Angle of Incidence Degrees	Wavelength Angstroms		
	8.34	13.3	44
0.5	X	X	
0.92		X	X
1.5	X	X	X
2.0	X	X	X
4.0			X

Each of the four (4) samples was also tested at 8.34 Å and at 0.92° angle of incidence for three additional angular orientations about an axis normal to the sample surface: 45°, 90°, and 180° from the 0° (Phase I) position. The products of Phase II of this program were the data recorded in the various tests. The following

paragraphs describe the tests and these data.

WAVELENGTH AND ANGULAR DEPENDENCE TESTS

The scattering of x-rays by polished optical flats were measured by means of a special vacuum line which was approximately 36 feet long. The experimental configuration of the x-ray scattering measurement equipment is shown in Figure 1. The vacuum system consisted of three stainless steel chambers, each 24 inches in diameter and 12 inches high. The three chambers were interconnected by 6 inch I.D. stainless steel tubing. The distance between the center line of each chamber was 17.2 feet. The middle chamber housed the sample and secondary detector with one end chamber enclosing the x-ray source and the other end chamber enclosing the detector used for measuring the reflected x-ray beam.

The x-ray sources used in this phase of the program along with the anode voltage and anode current are as follows: (1) aluminum (8.34 \AA), 3 KV, 40 ma, (2) copper (13.3 \AA), 1.8 KV, 40 ma, and (3) carbon (44 \AA), 1.4 KV, 50 ma. The x-ray source is a demountable, continuously pumped design consisting of a filament enclosed by a focusing cup mounted on insulators above an anode operated at ground potential. The sources used in these measurements had exchangeable anodes that were selected to produce the desired x-ray wavelengths given above. The angle between the direction of the x-ray beam and the anode surface is 15° . A 0.002 inch slit is

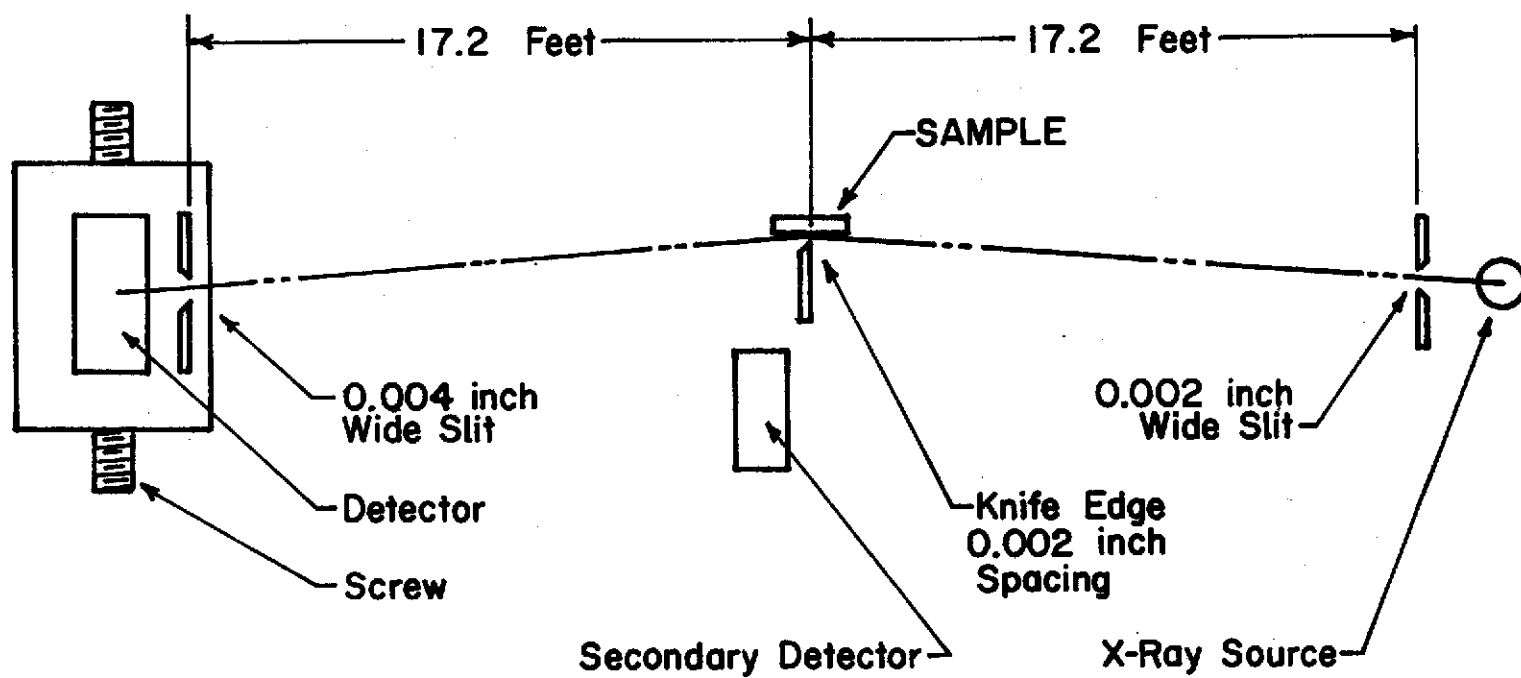


Figure 1 - Schematic of Scattering Equipment

mounted directly in front of the anode to accurately define the width of the source. The purpose of this slit and the slits at the sample and detector were to yield a theoretical FWHM value of the scattering curves which, when compared to the experimental FWHM value, would give an indication of the amount of scattering produced by the surface imperfections of the sample.

In the middle chamber, 17.2 feet away from the x-ray source, the sample was mounted in the sample holder which could be rotated in one arc minute steps in either direction about an axis parallel to the sample surface and perpendicular to the incoming beam. A secondary detector was placed adjacent to the sample holder to monitor the direct beam from the x-ray source so that any variations that occurred at the source could be taken into account in the final analysis of the scattering data. A beam stop with a one inch diameter hole was placed directly in front of the sample between the sample and the primary detector end of the system. The beam stop helped reduce the amount of x-rays scattered from the chamber walls and x-rays from the direct beam from reaching the primary detector. In the end chamber, 17.2 feet from the sample, the primary detector was placed on a mount that could translate across the reflected x-ray beam in 0.1 arc second intervals. The primary detector was a flow type (P-10 gas) proportional counter with a 2 micron thick Makrofol window. A 0.004 inch wide slit was placed directly in front of the window of the detector.

The system was aligned by means of a laser so that the angle of incidence between the sample and the x-ray source was the proper value. After the sample and the primary detector were put in position, the chamber was closed and the pressure reduced to approximate 2×10^{-6} Torr. The high voltage for the x-ray source was then turned on and the scattered beam was located. After the peak of the scattered beam was located, the primary detector was positioned +30 arc seconds from the peak. A typical run consisted in translating the detector and slit across the scattered x-ray beam in one arc second intervals and counting for 100 seconds at each point from +30 arc seconds to -30 arc seconds.

Two types of data were collected for each sample. The first was a scan of intensity values as a function of angle as the detector was scanned across the reflected beam. Readings were taken every arc second so that a detailed shape of the scattering curve could be determined. These curves were expected to be symmetrical, but the results indicated that they were not always regular in shape. These curves were used to find the position of the peak reflected intensity, and the width of this peak was interpreted as a characteristic of the sample. The second type of data consisted of readings taken at nine selected points (0, ± 5 , ± 10 , ± 20 , ± 30 arc seconds) about the peak. These points were used in making calculations of the percentage of radiation scattered away from the main reflected beam.

DATA FORMAT

The experimental configuration used in this phase of the program had the source slit set at .002 inch, the sample slit set at .002 inch (equivalent to .004 inch), and the detector slit set at .004 inch.

From geometrical considerations, assuming no scattering, the x-ray beam reflected from the sample should have a trapezoidal intensity profile that has an eight arc second FWHM. The 17.2 feet working distance was chosen so that one arc second was equal to .001 inch of linear motion. The value S_w was defined as the difference between the observed curve width (FWHM) and the calculated width (FWHM) based on geometrical considerations. Negative values of S_w are thought to be due to error in setting the slits or in the motion of the system during the course of a run. The error in S_w is about ± 2 arc seconds.

As shown in the graphs in Figures 2-45, the negative angles are in a direction away from the surface of the sample. The failure of the nine points data to be exactly symmetrical should be interpreted as an uncertainty in the position of the detector. This positional uncertainty in locating the peak was ± 3 arc seconds, but the relative locations of the nine points were uncertain by less than ± 1 arc second.

SCATTERING CURVES

Figures 2 through 45 show the relative intensity curves for the wavelength and angular dependence tests obtained from the 61 point raw data. Each individual graph contains an identification number in the right hand corner, for example on Figure 2, the number is (G2) 2-8-0.5 (0°). The code for the number is as follows:

(G2) - indicates Phase II program of NAS5-23198

2 - indicates sample number

8 - indicates wavelength (Angstroms)

0.5 - indicates angle of incidence (degrees)

(0°) - indicates angular orientation of sample in sample holder

Each graph also contains a value representative of the scattering width in arc seconds, designated as S_w . This value was defined as the difference between the observed curve width (FWHM) and the calculated width (FWHM). Compilation of the scattering widths are given in Table 6. Throughout the wavelength and angular dependence tests, all samples were placed in the sample holder at a definite orientation. This orientation was defined as 0° (angular orientation about an axis normal to the sample surface) and determined for the sample by an arrow on the side of each sample.

NINE POINTS DATA

The nine points data was processed so that tables showing relative intensities could be prepared. The intensity values at

the nine points were defined as:

I_{-4} = Intensity at -30 arc seconds

I_{-3} = Intensity at -20 arc seconds

I_{-2} = Intensity at -10 arc seconds

I_{-1} = Intensity at -5 arc seconds

I_0 = Intensity at peak value

I_1 = Intensity at +5 arc seconds

I_2 = Intensity at +10 arc seconds

I_3 = Intensity at +20 arc seconds

I_4 = Intensity at +30 arc seconds

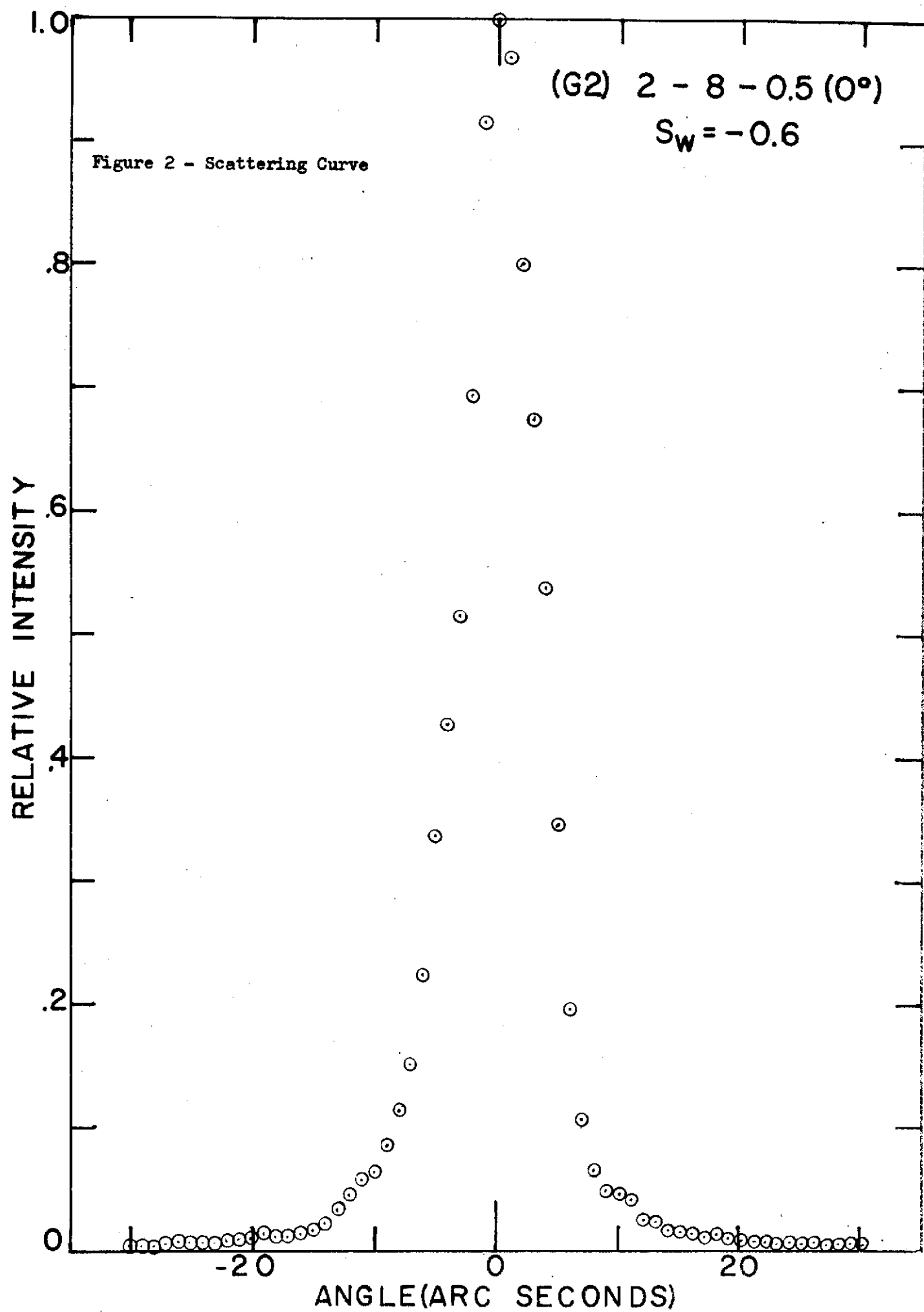
The relative intensity RI was then defined as:

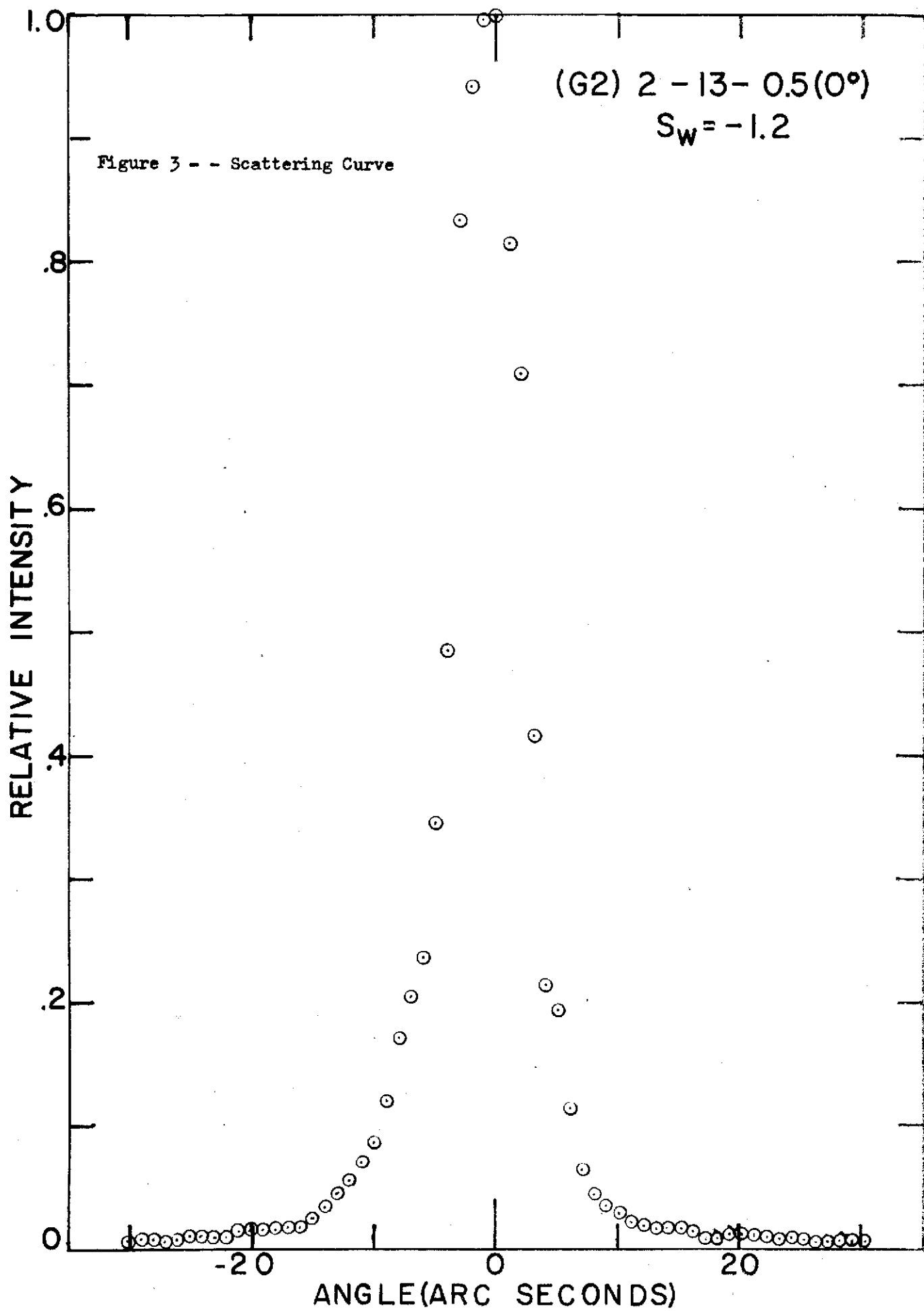
$$RI_j = I_j / I_0$$

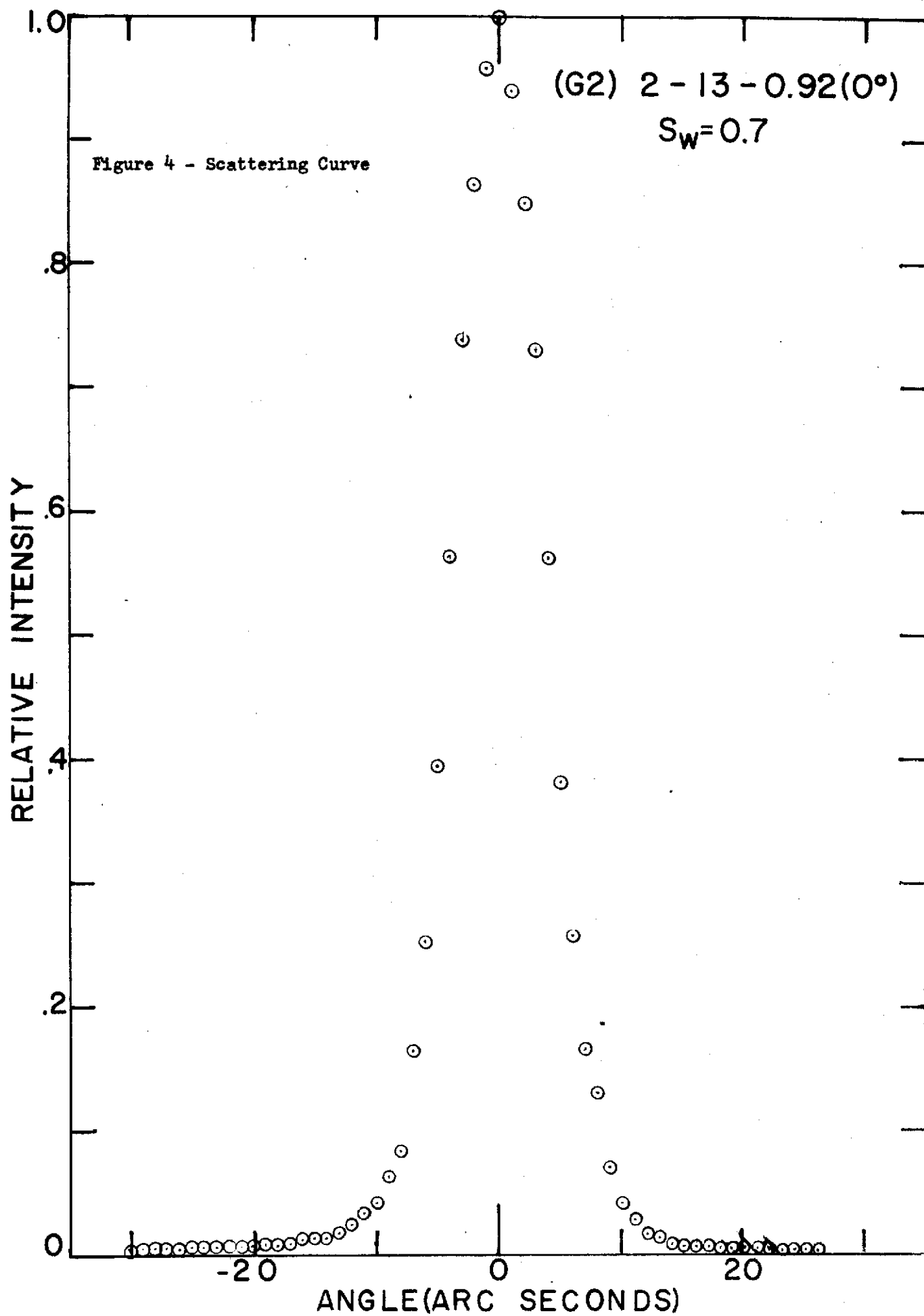
This definition produced a set of relative numbers which would then be compared with one another and these values are listed in Table 1 through 4.

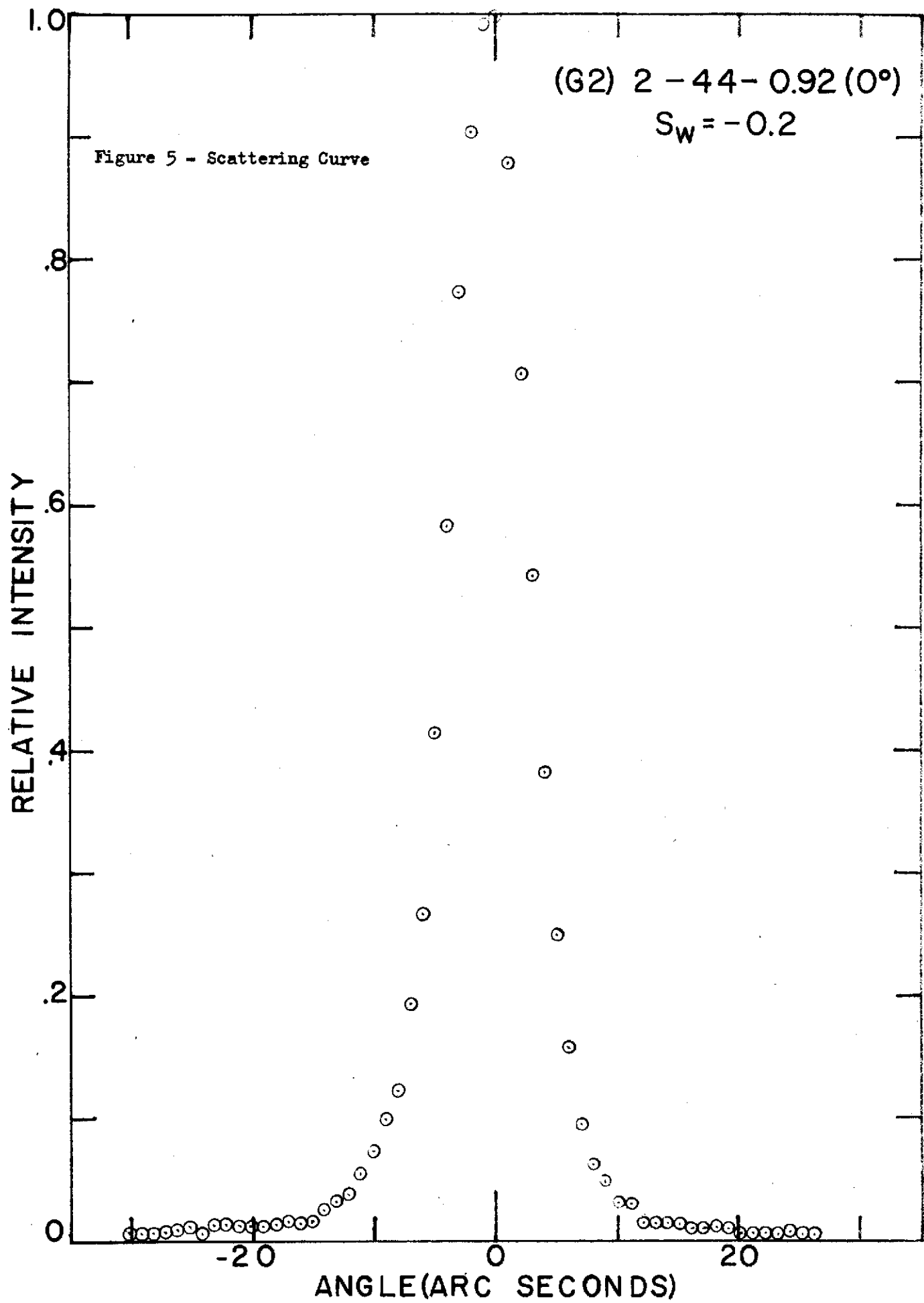
The percent scattered, S, was defined as:

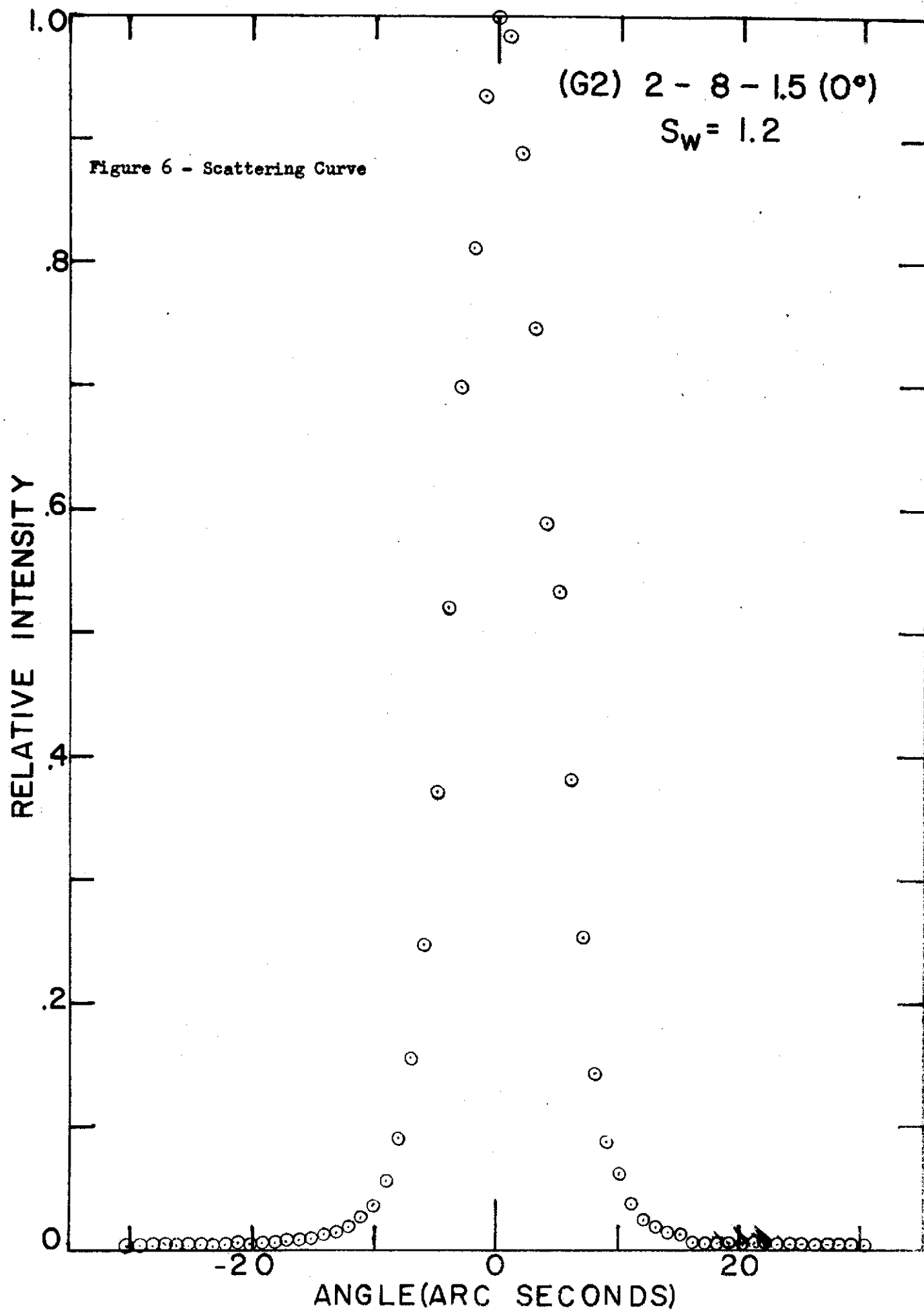
$$S = \left\{ \sum_{j=-4}^4 I_j - \sum_{j=-2}^2 I_j \right\} / \left\{ \sum_{j=-4}^4 I_j \right\}$$

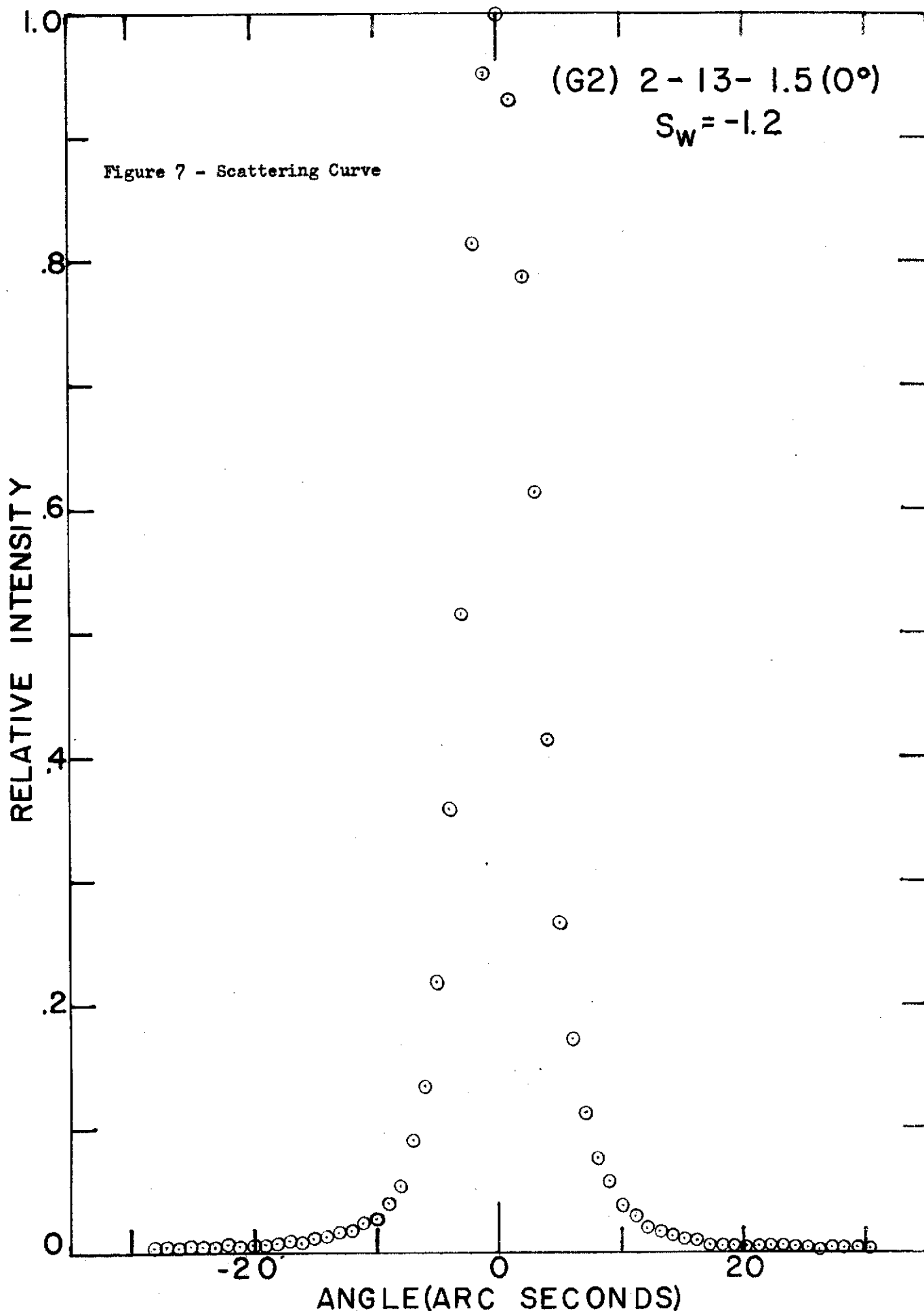


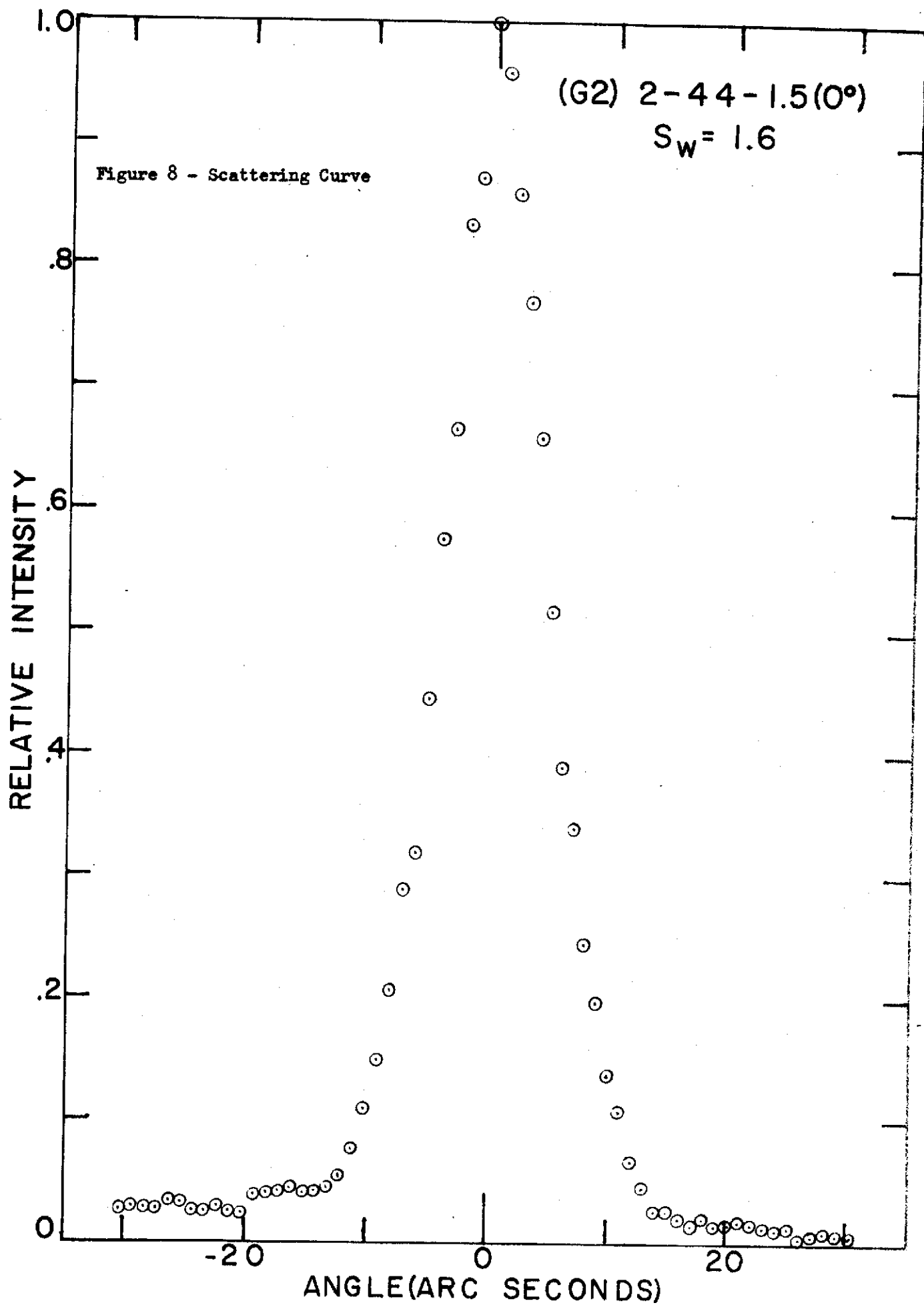


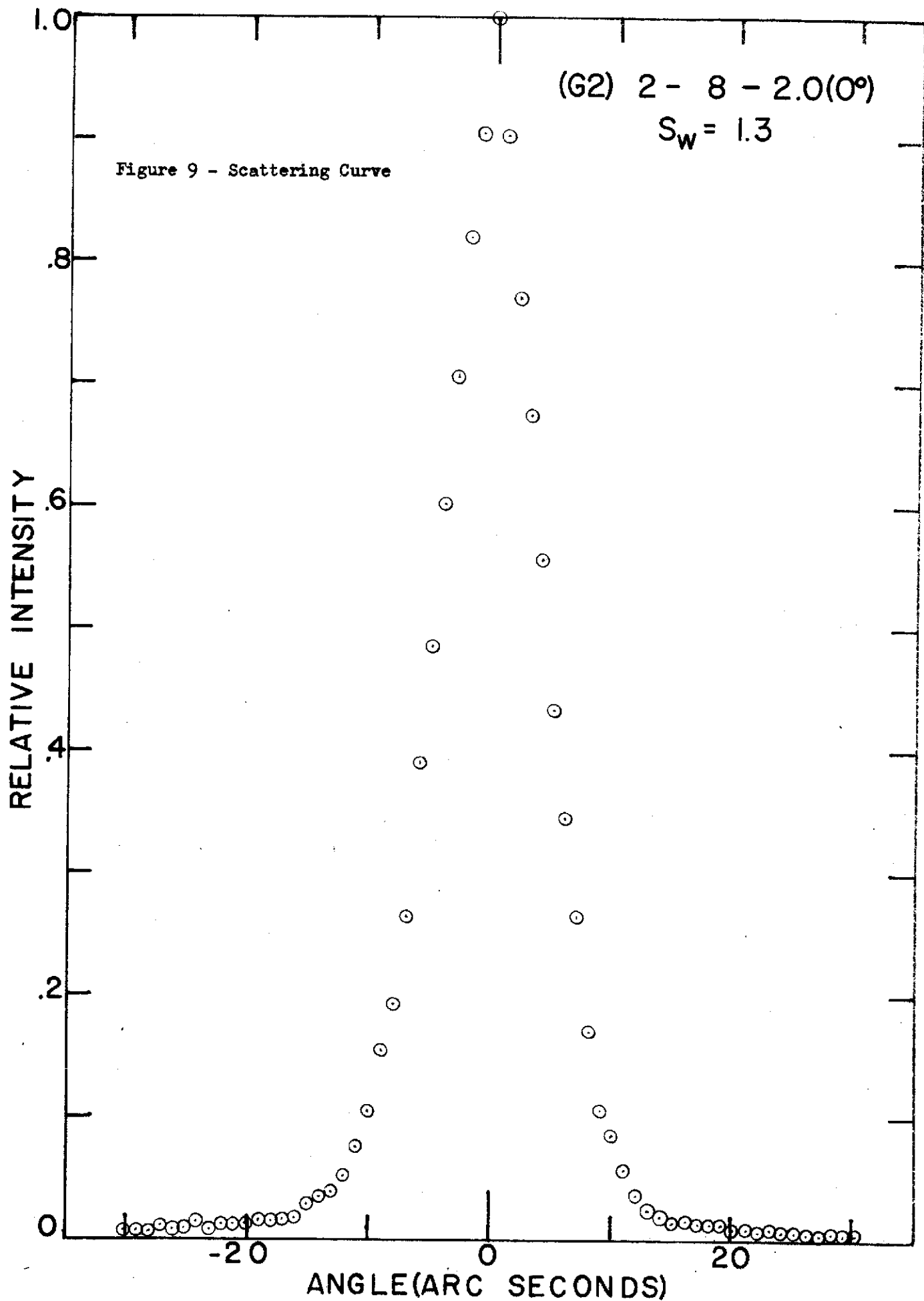


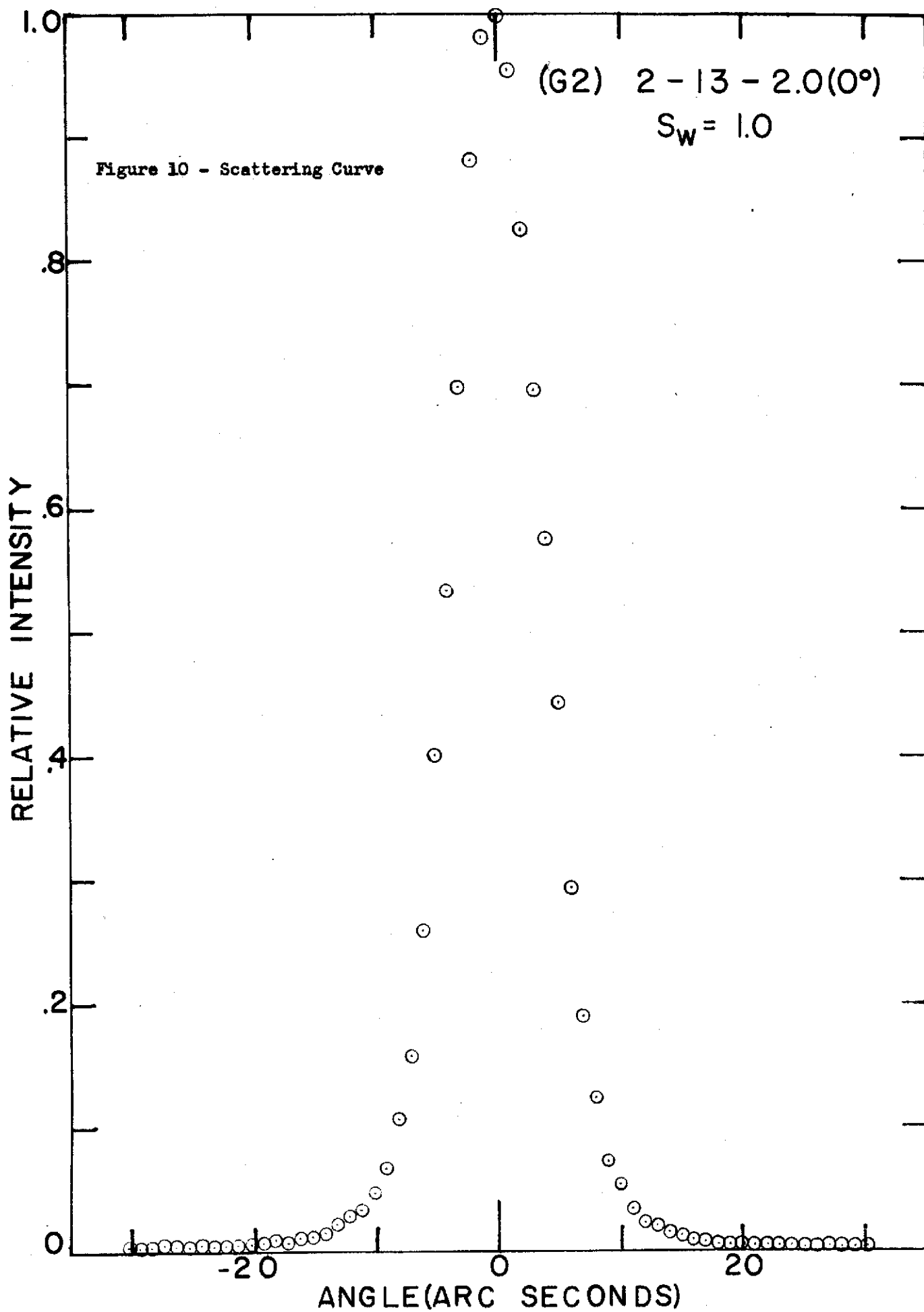


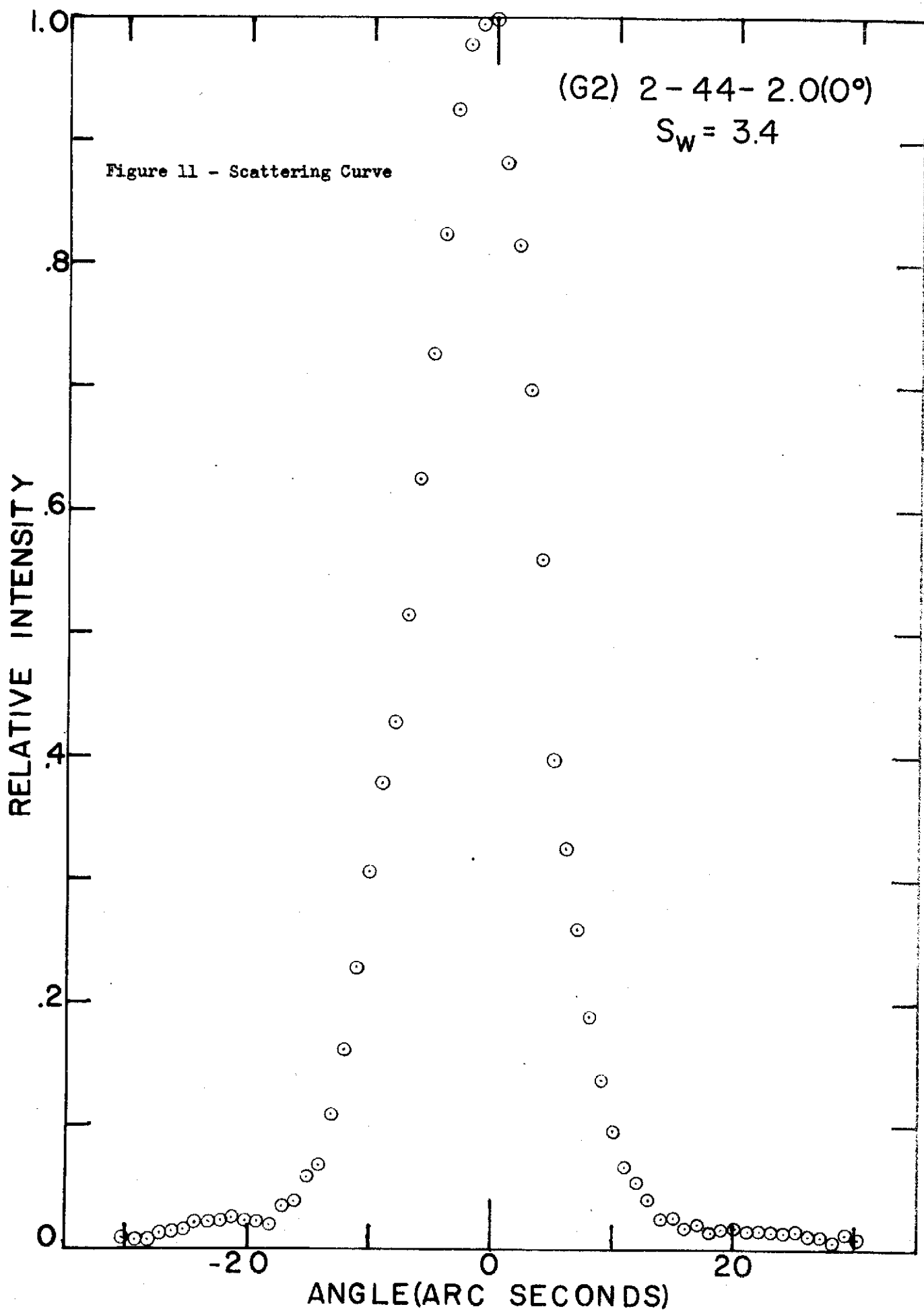


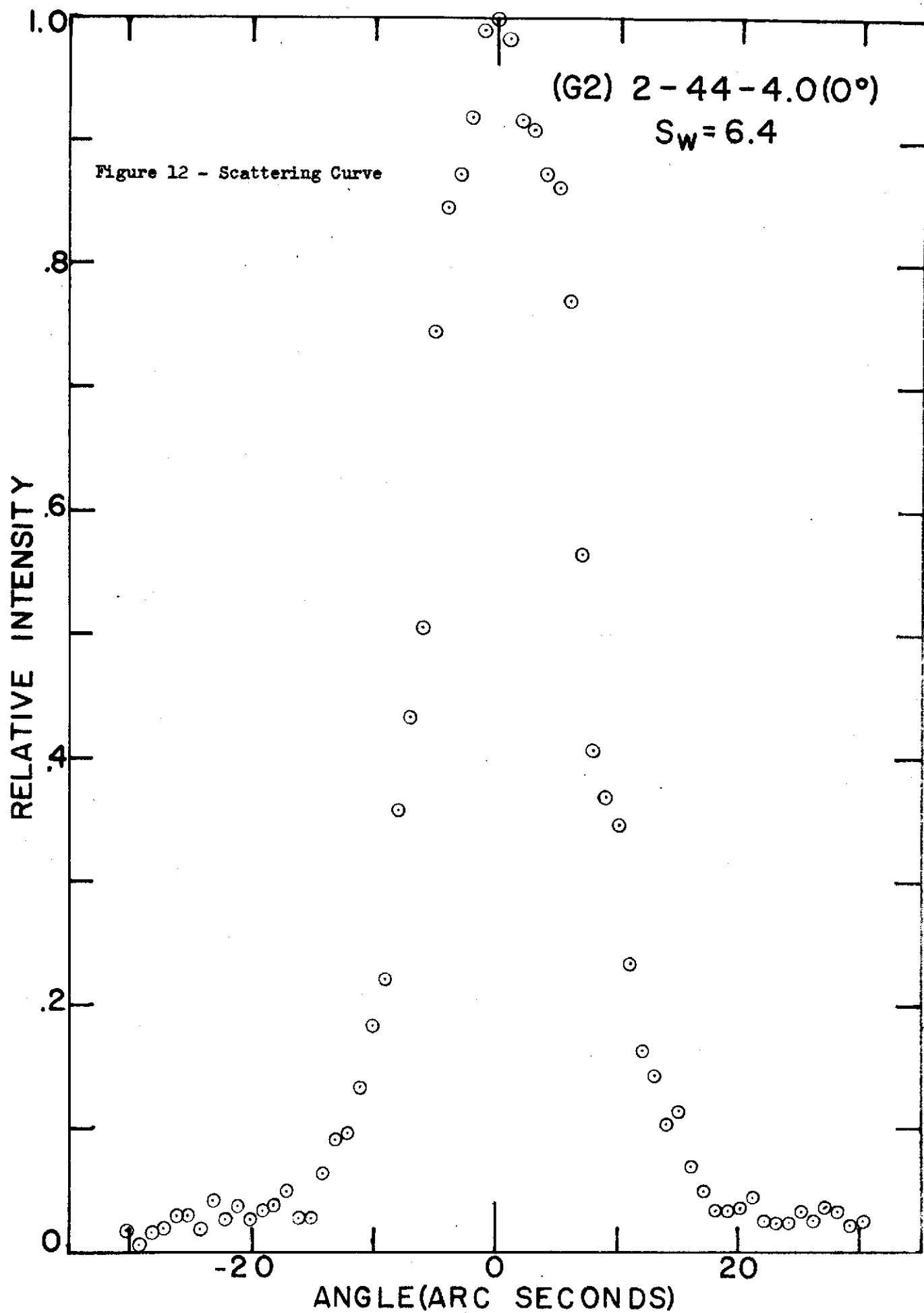


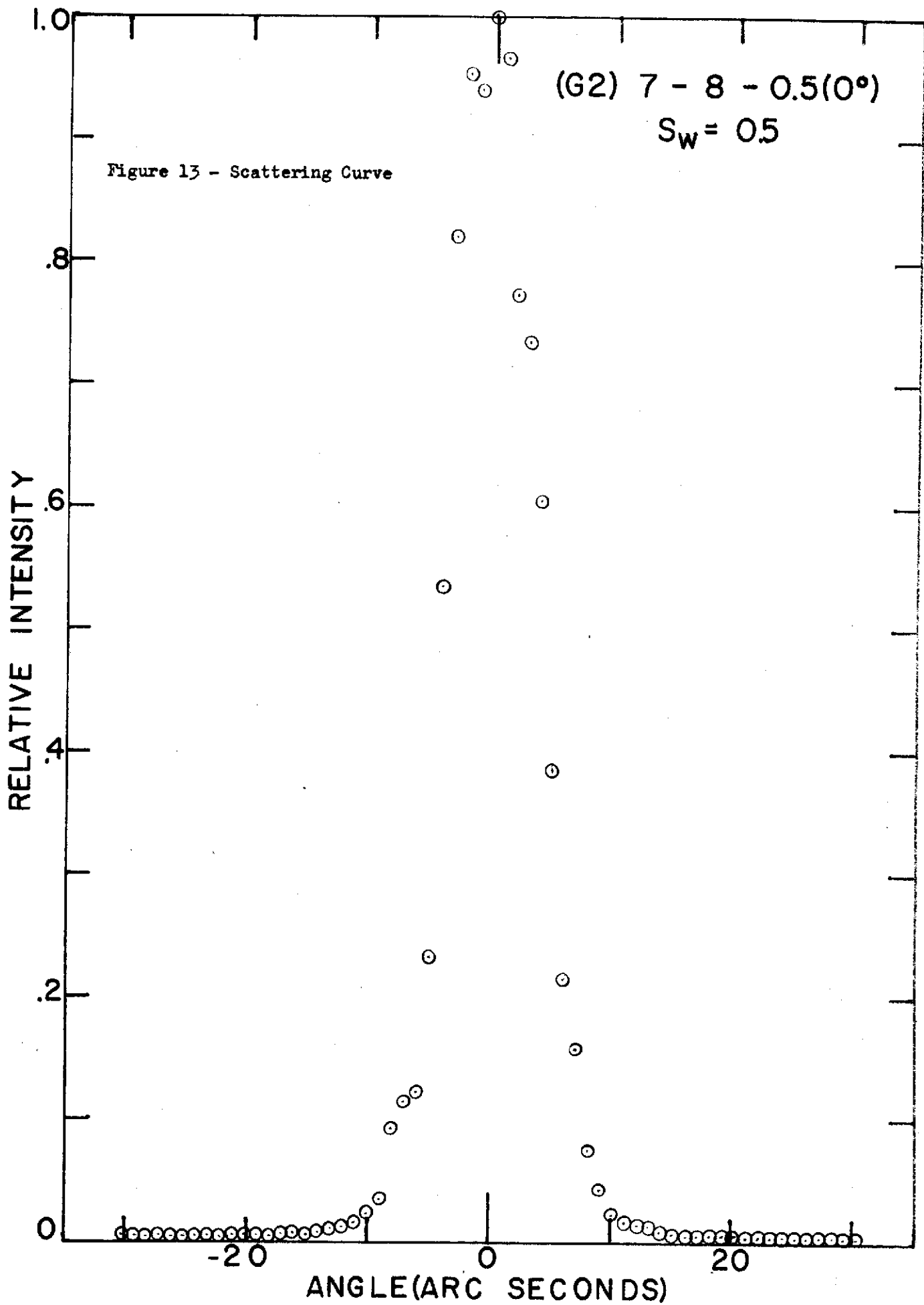


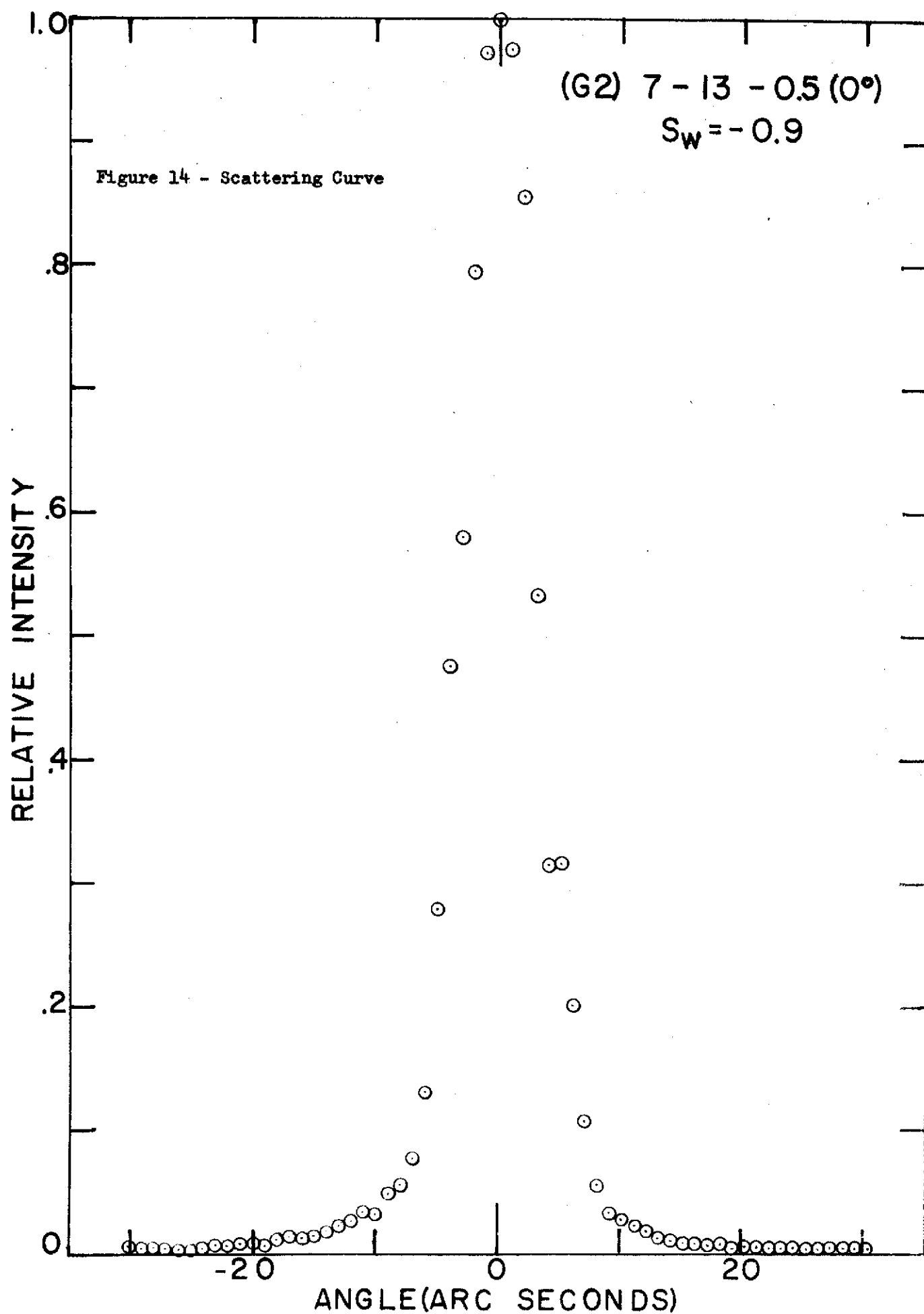


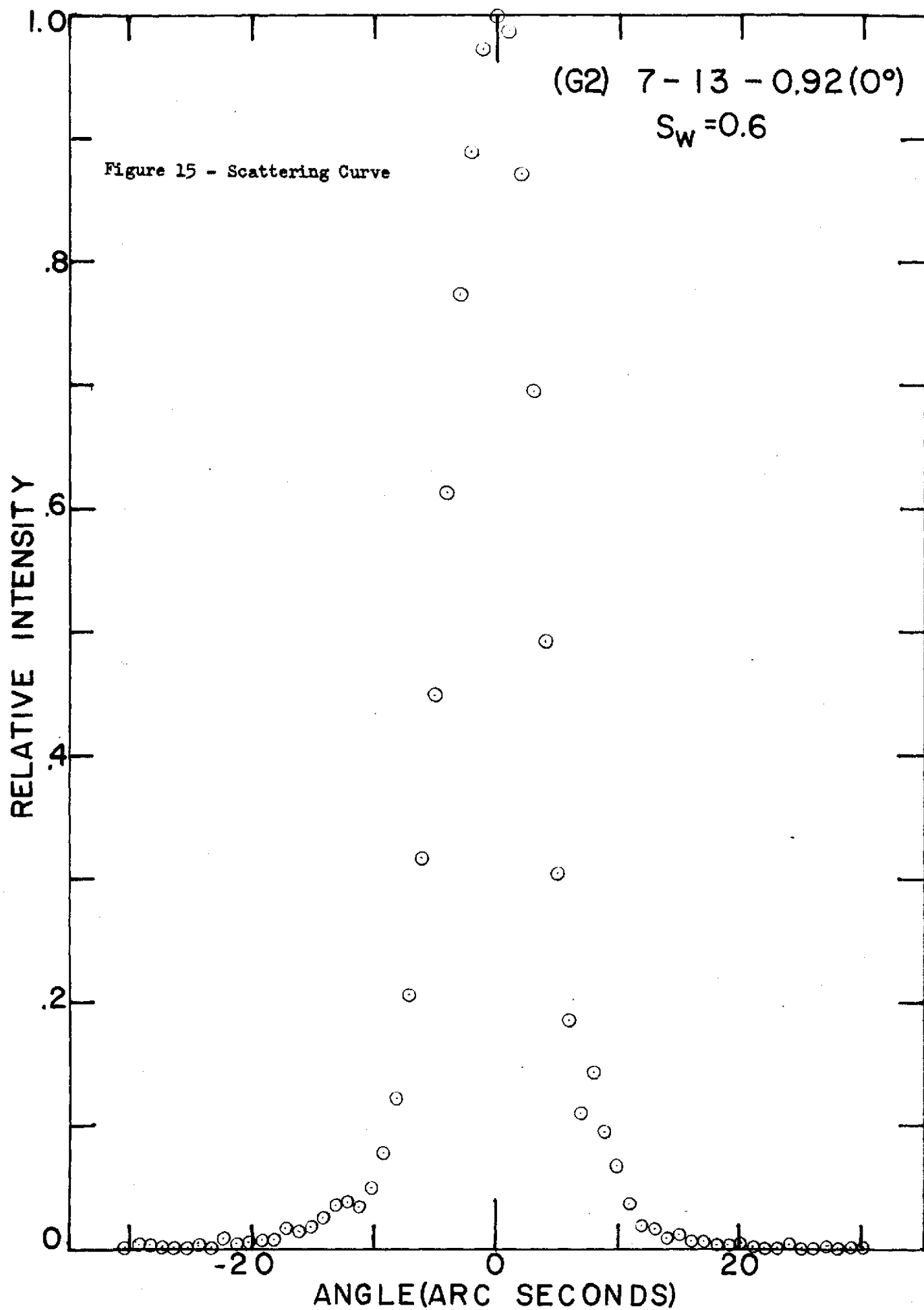


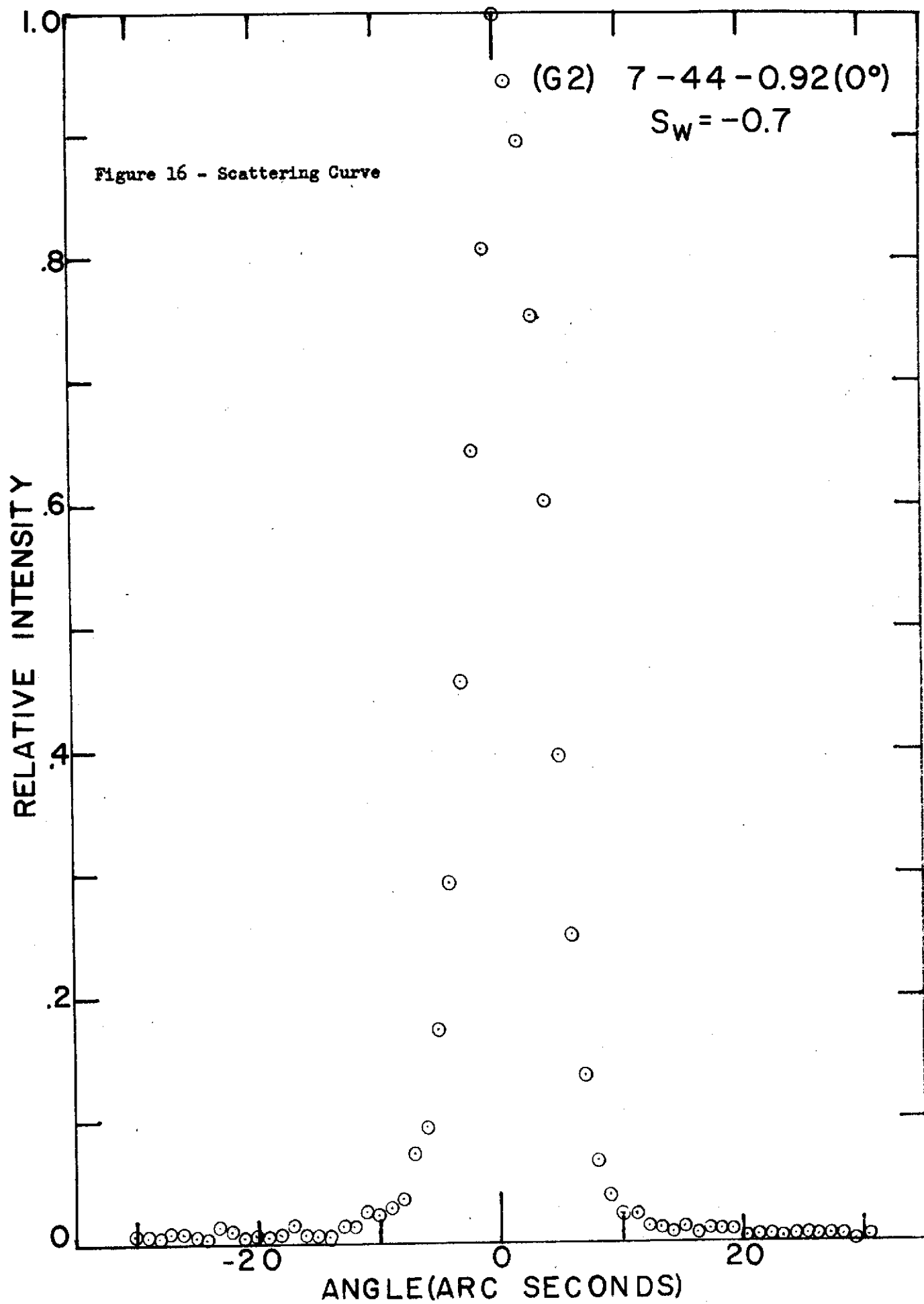


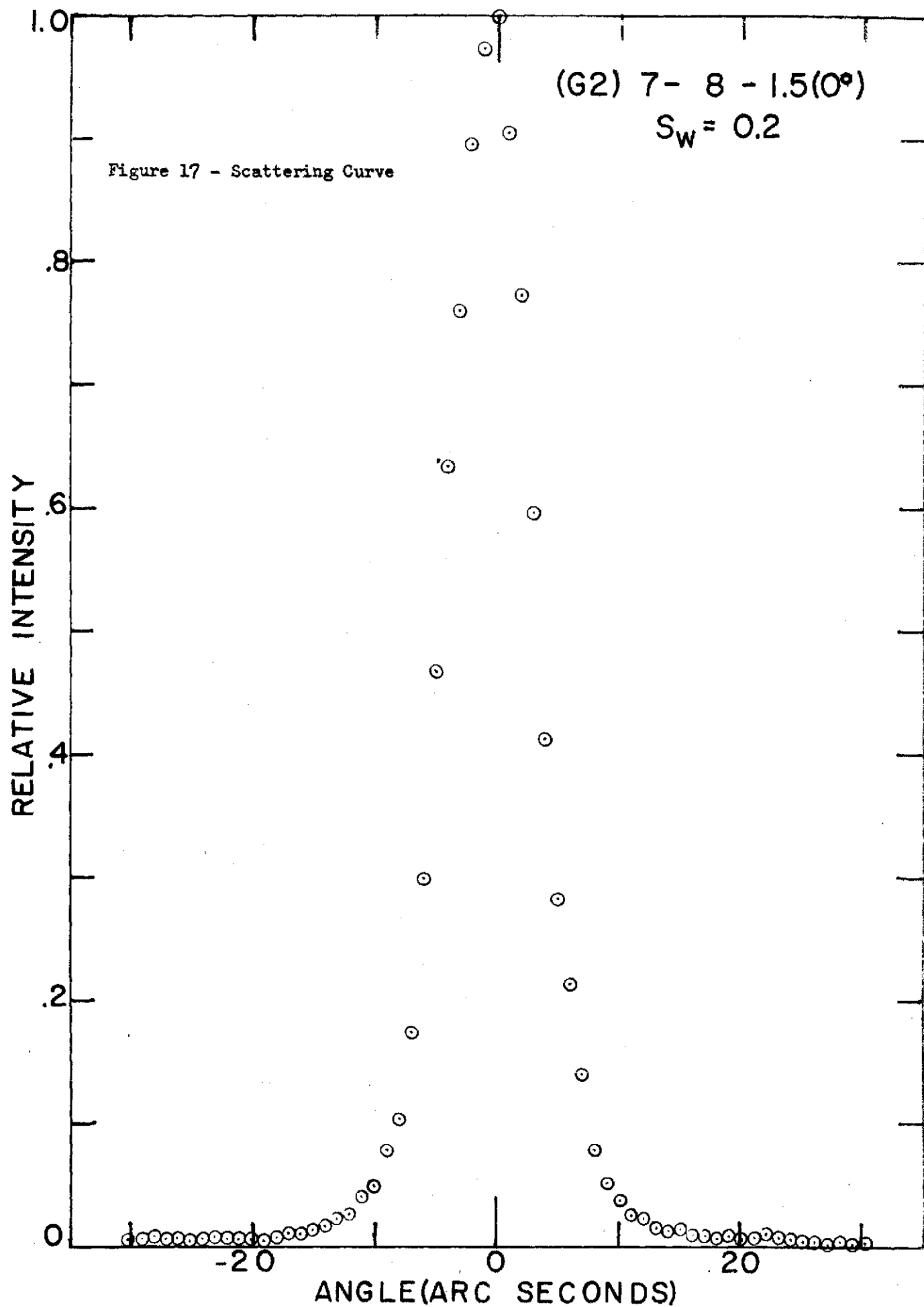


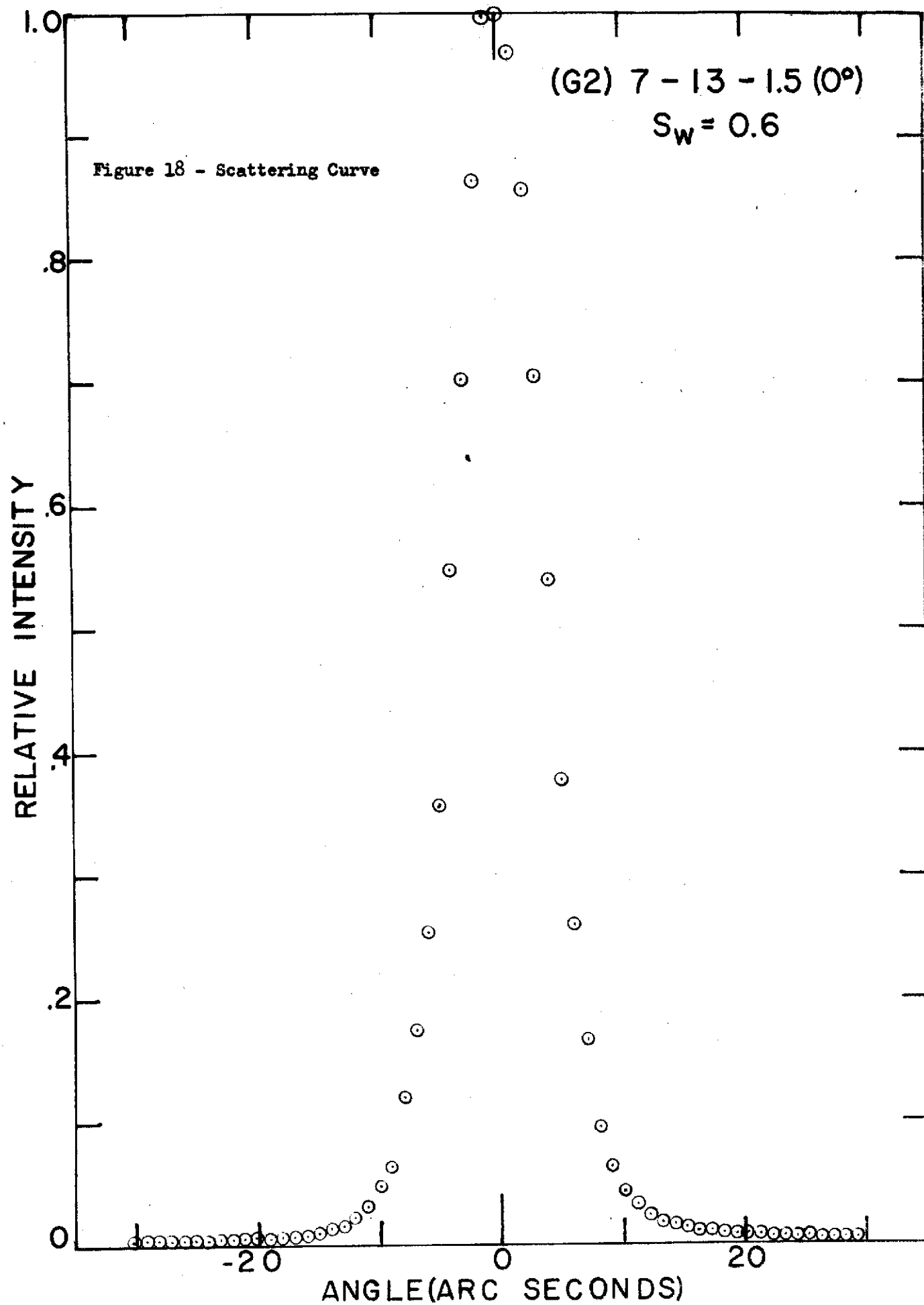


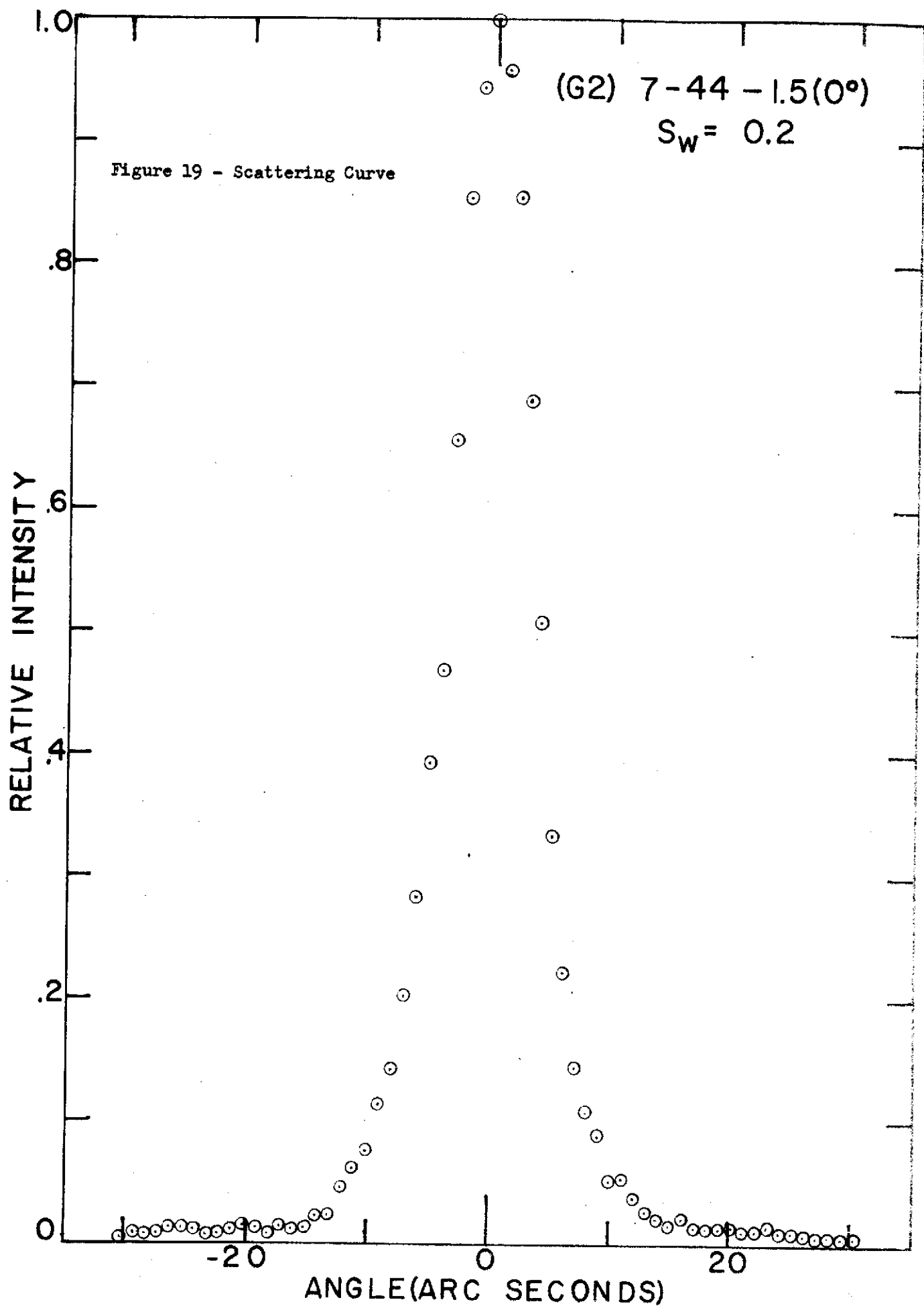


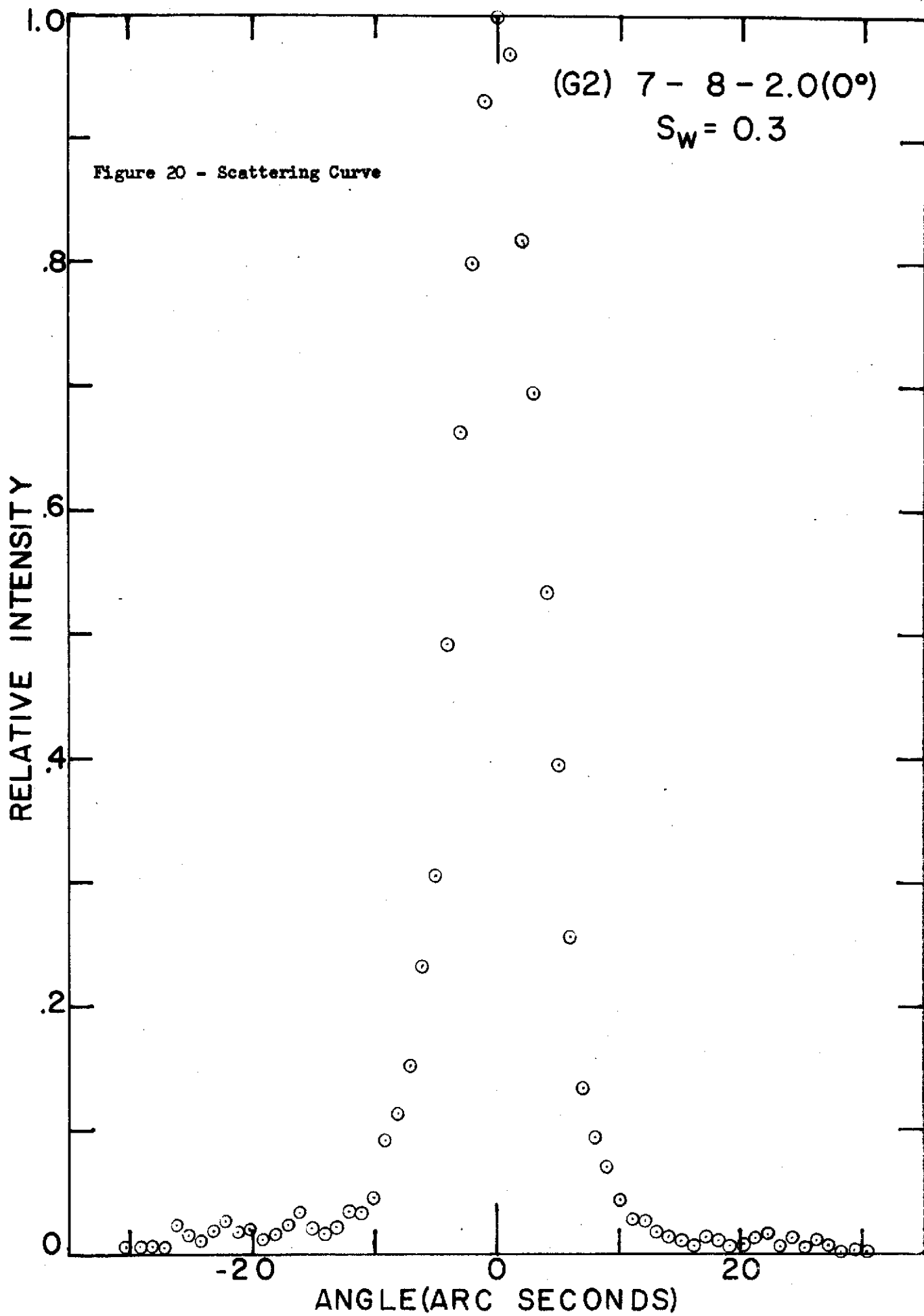


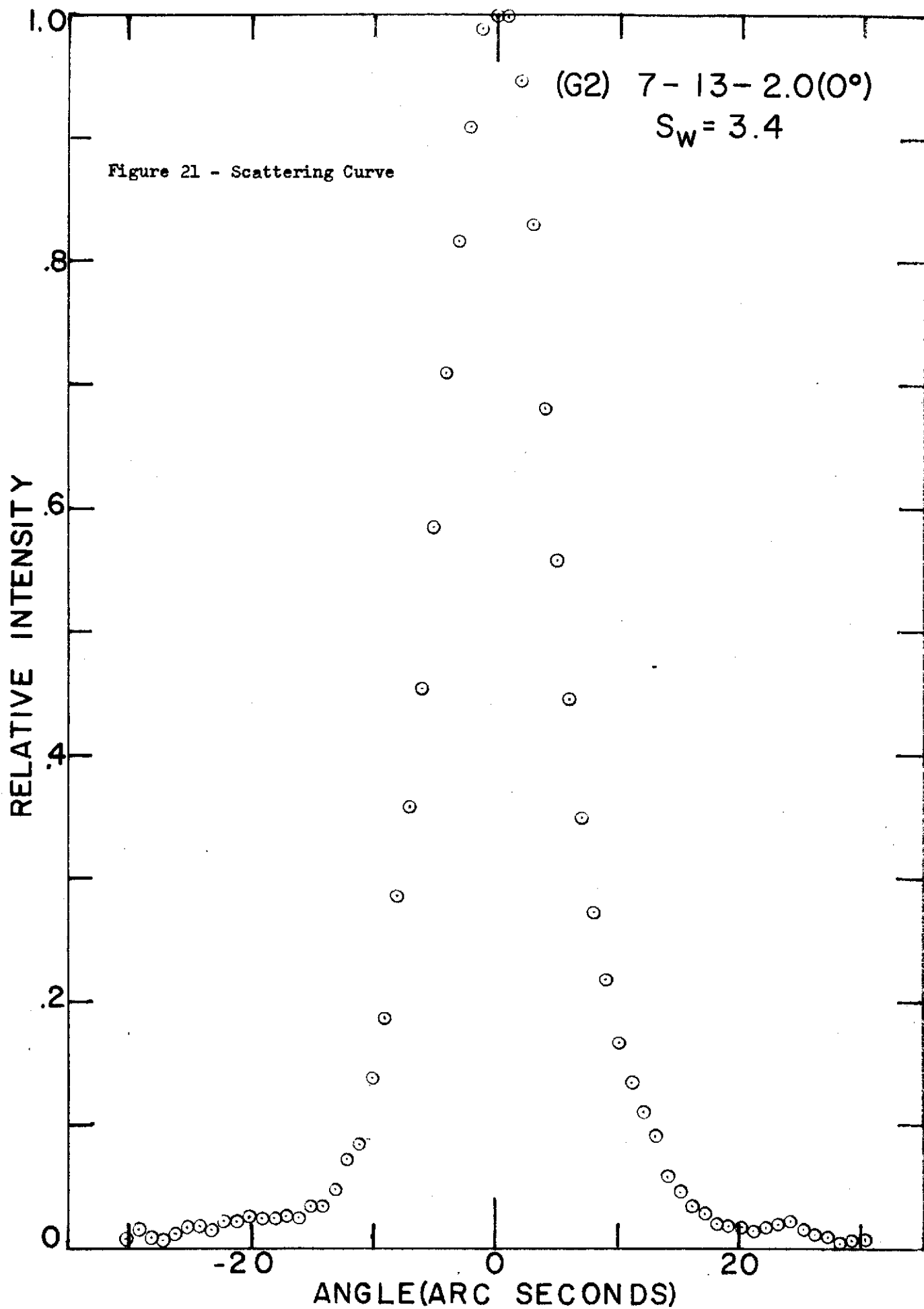


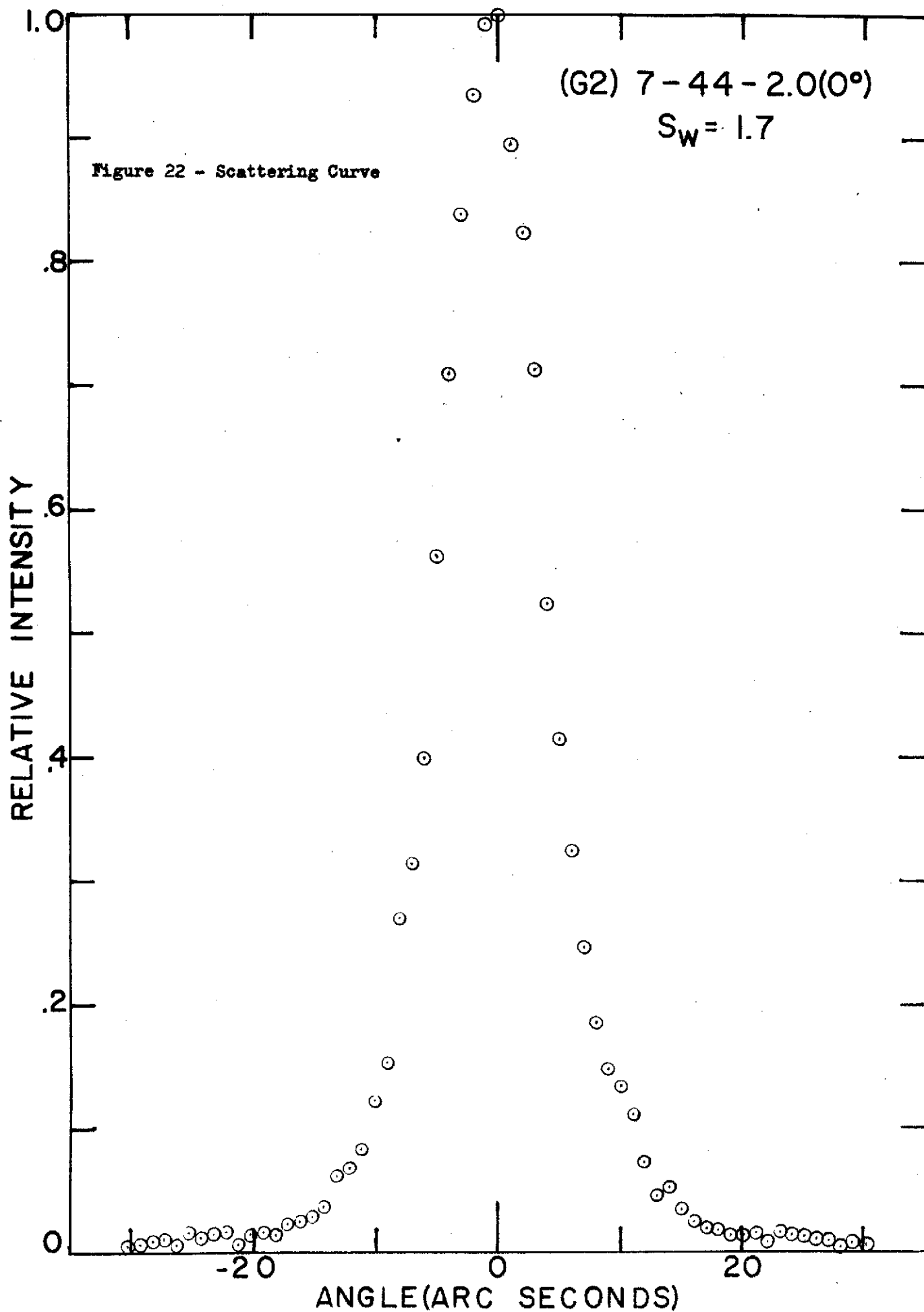


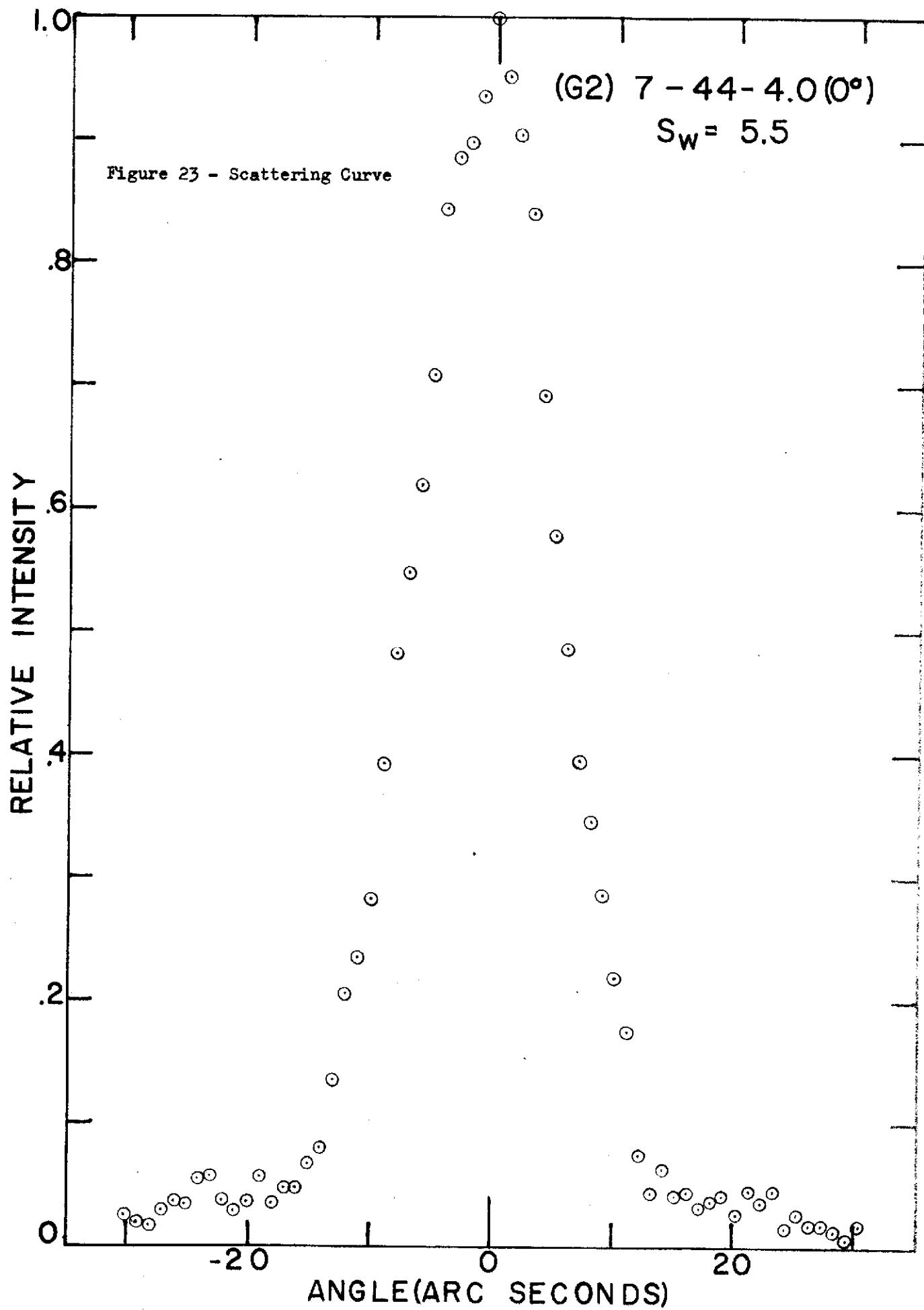


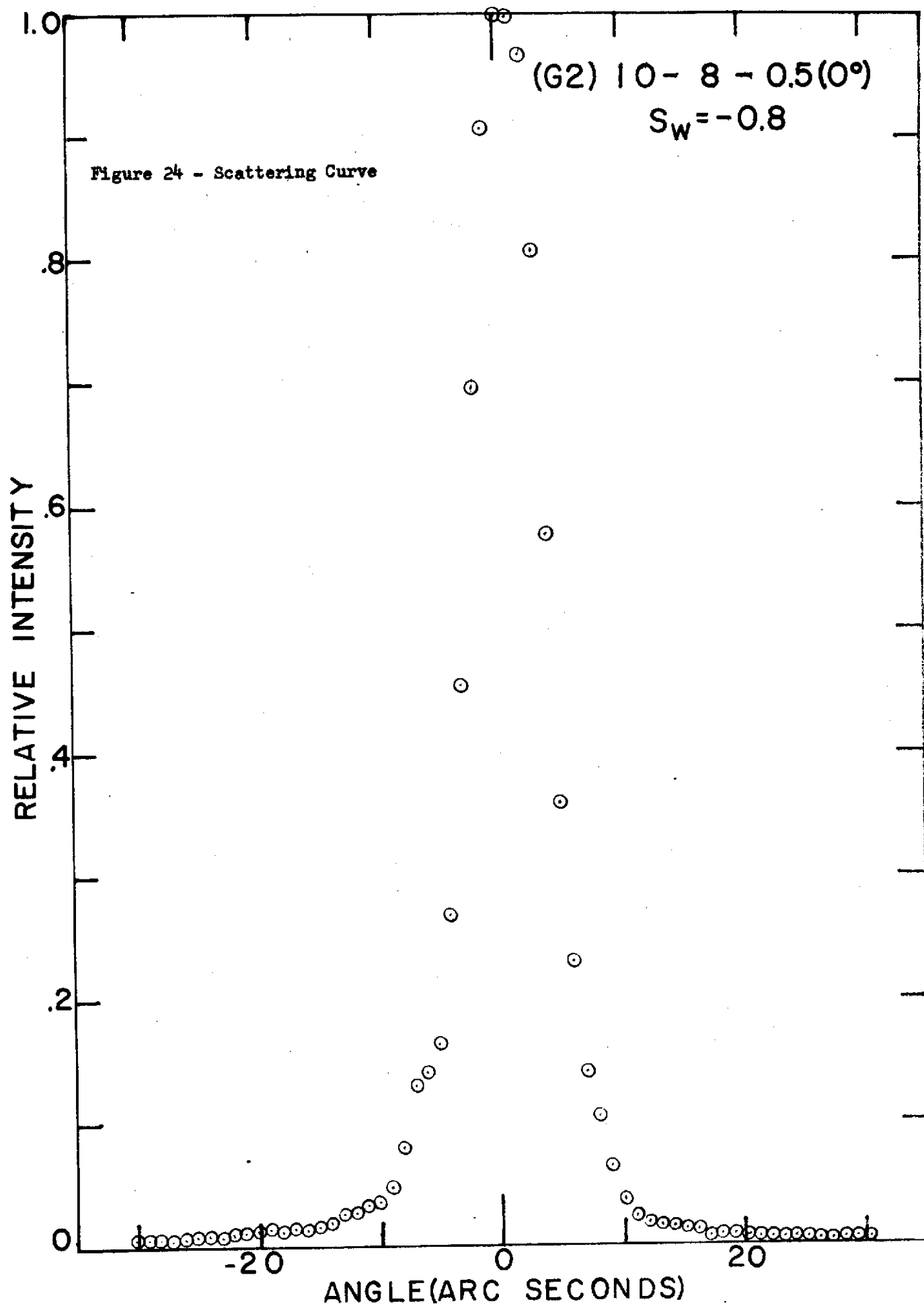


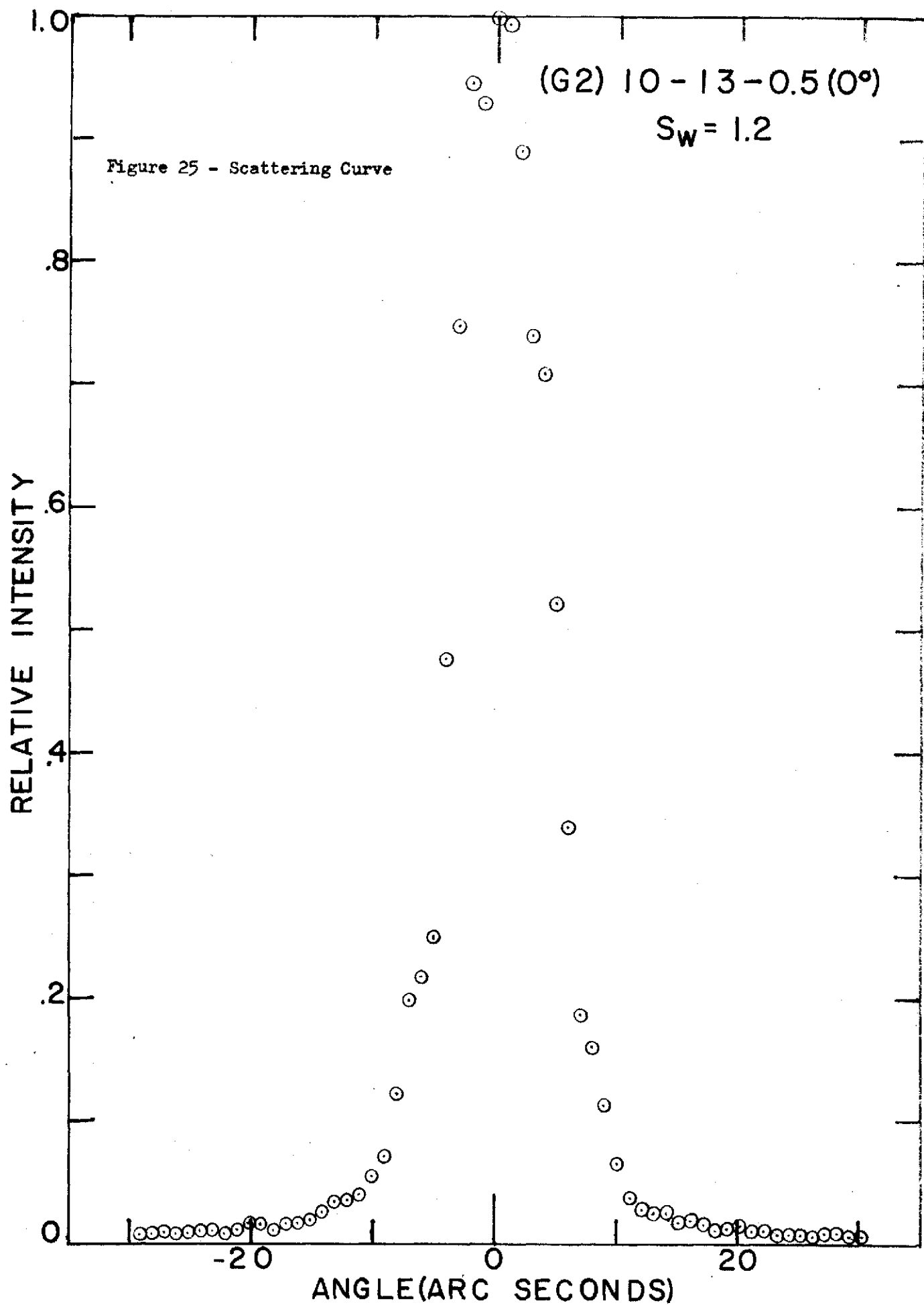


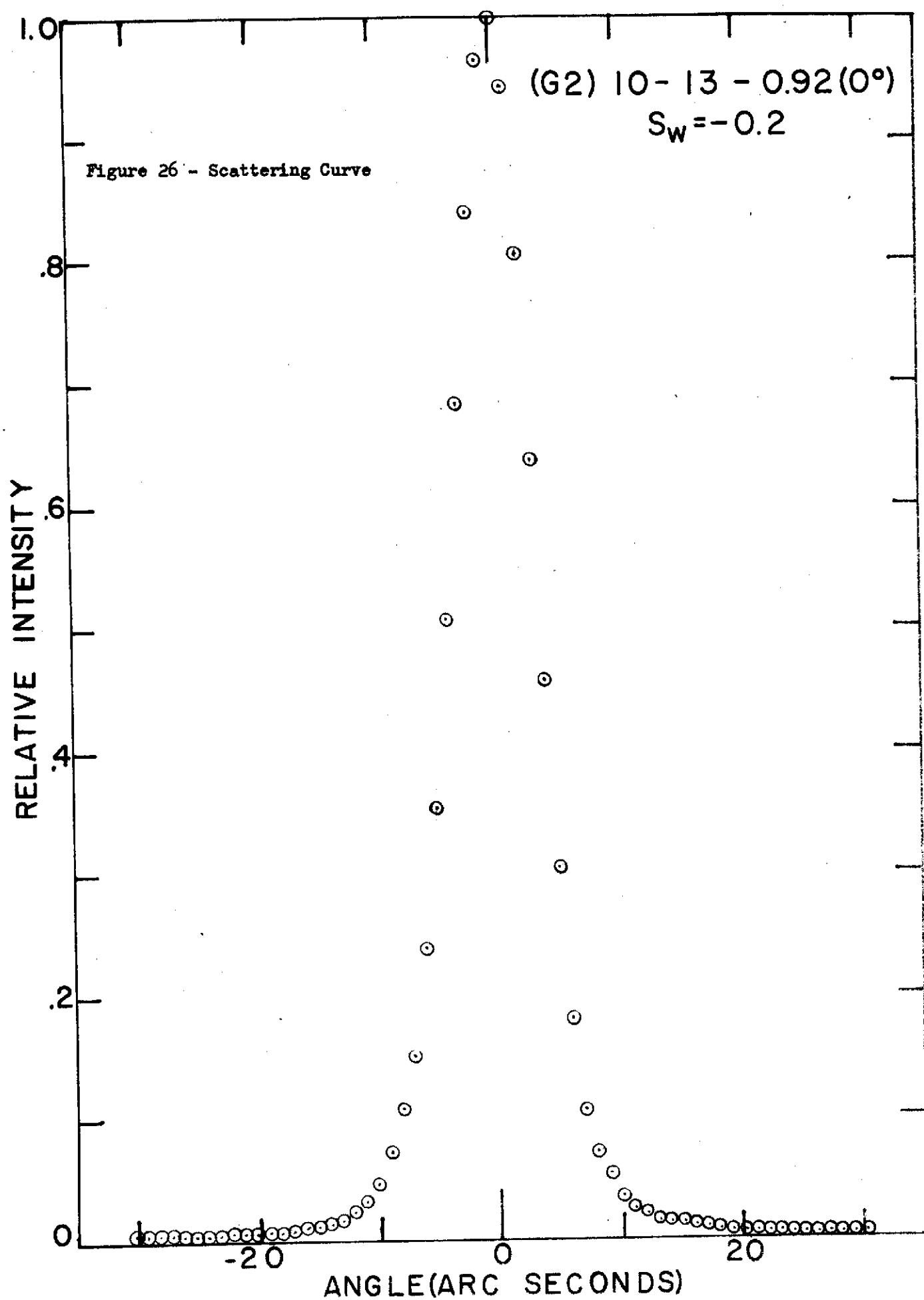


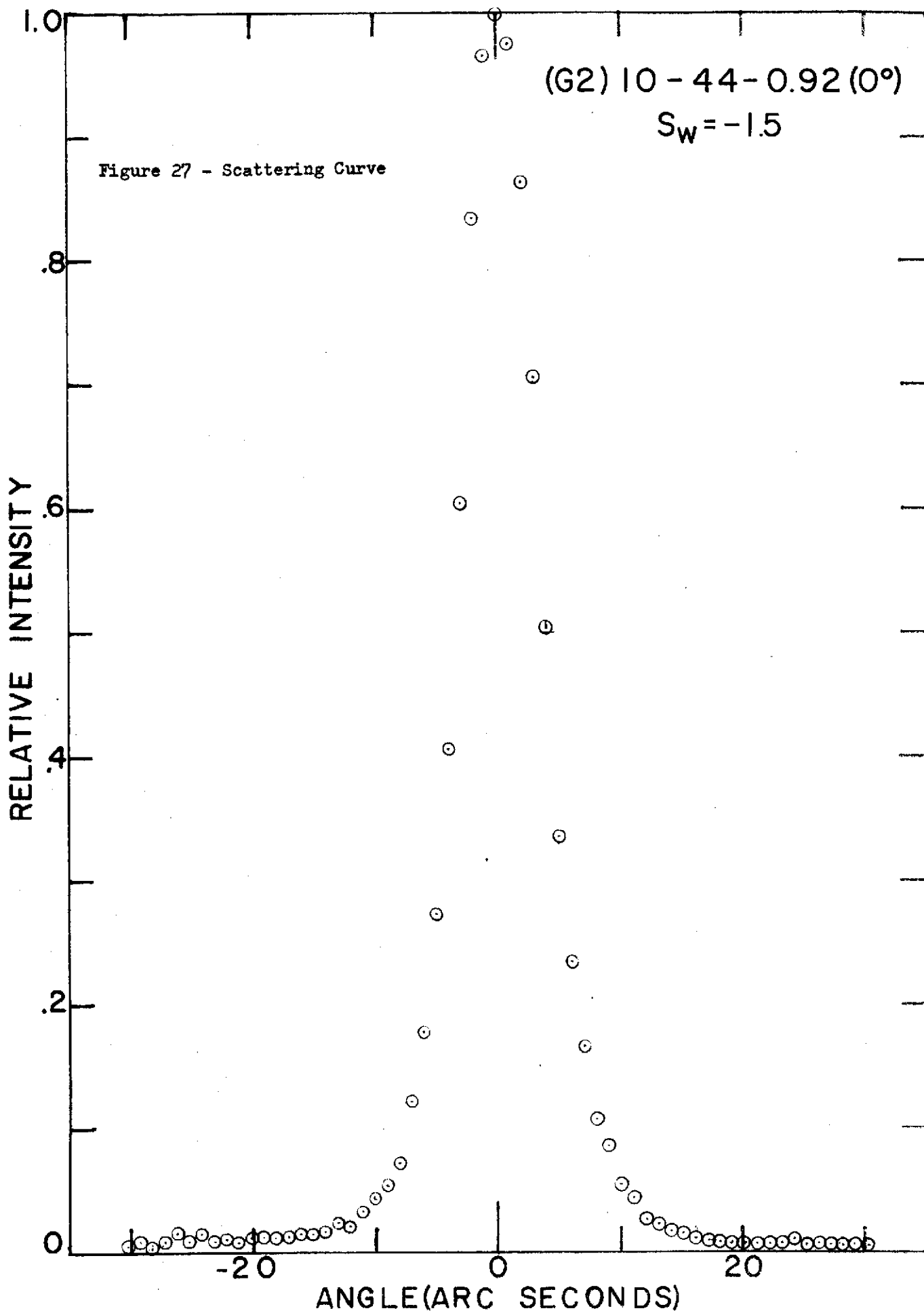


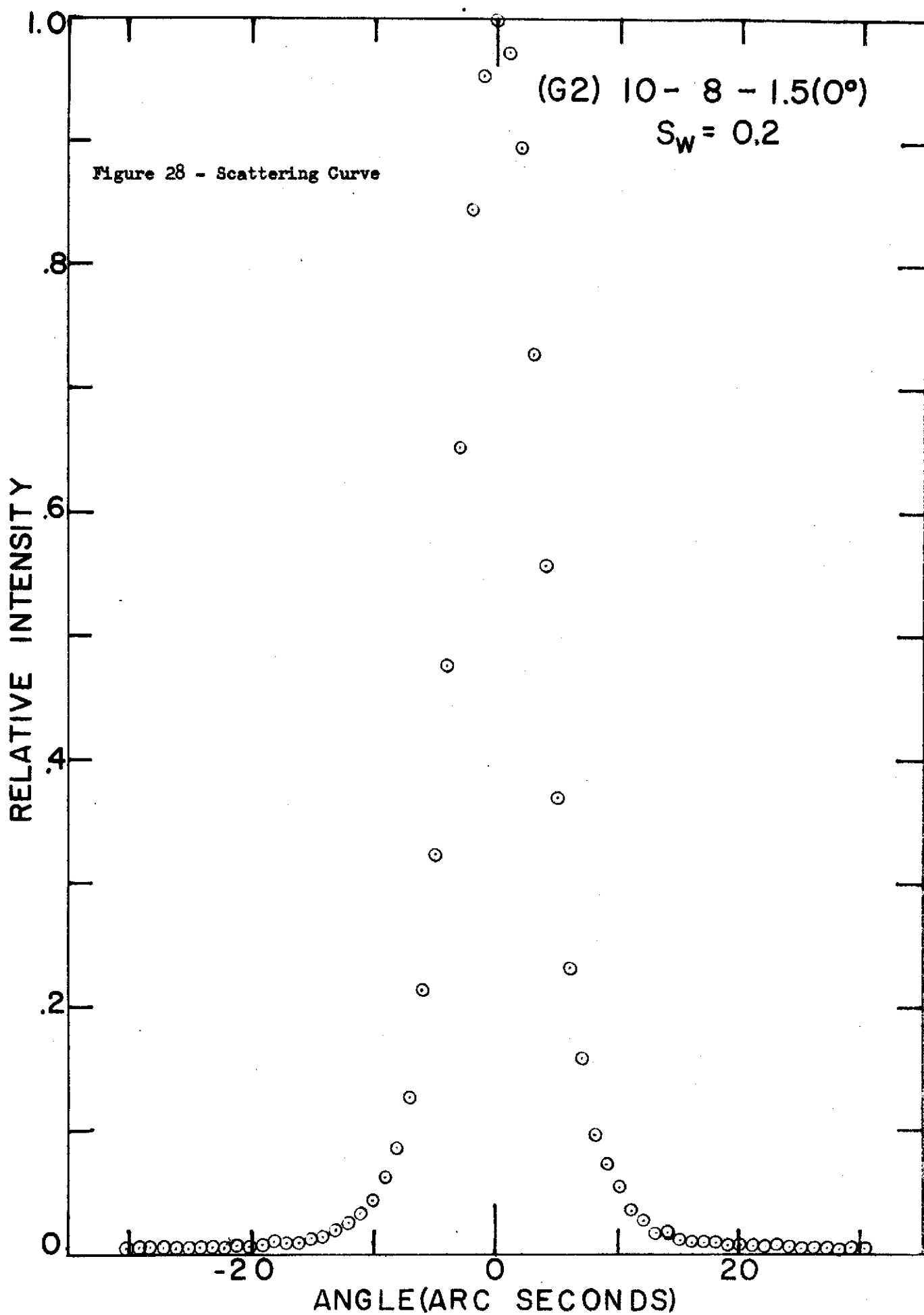


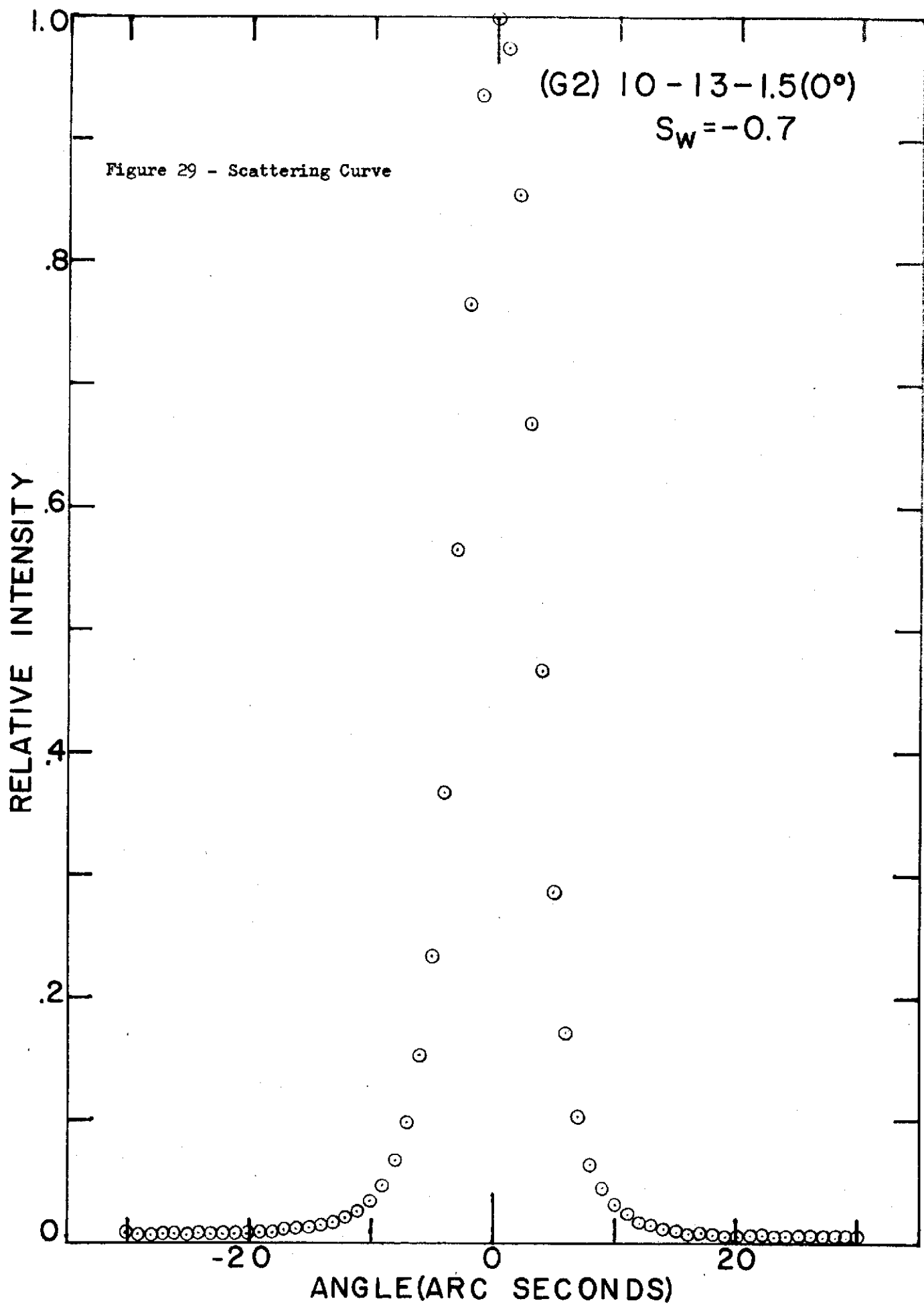


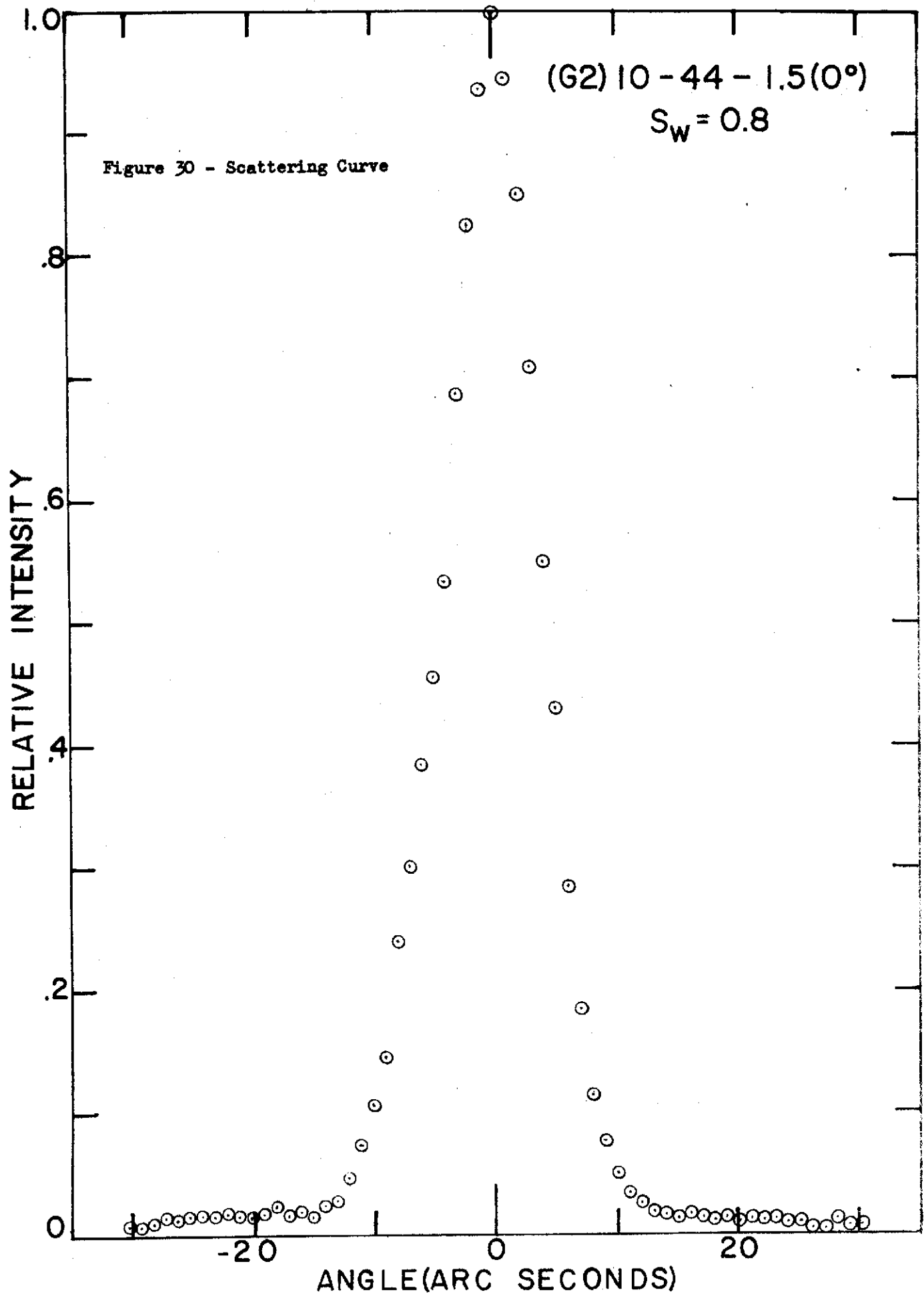


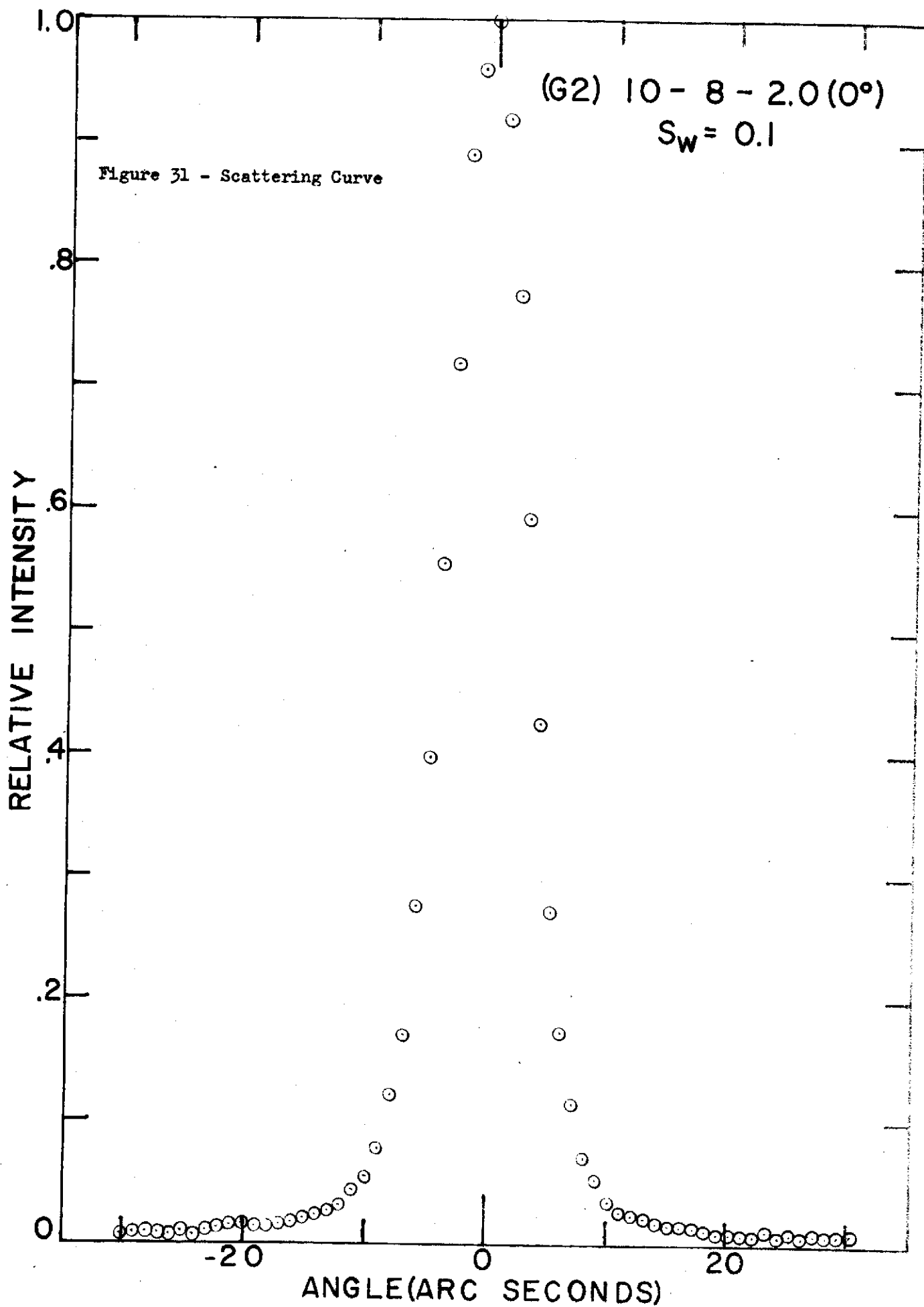


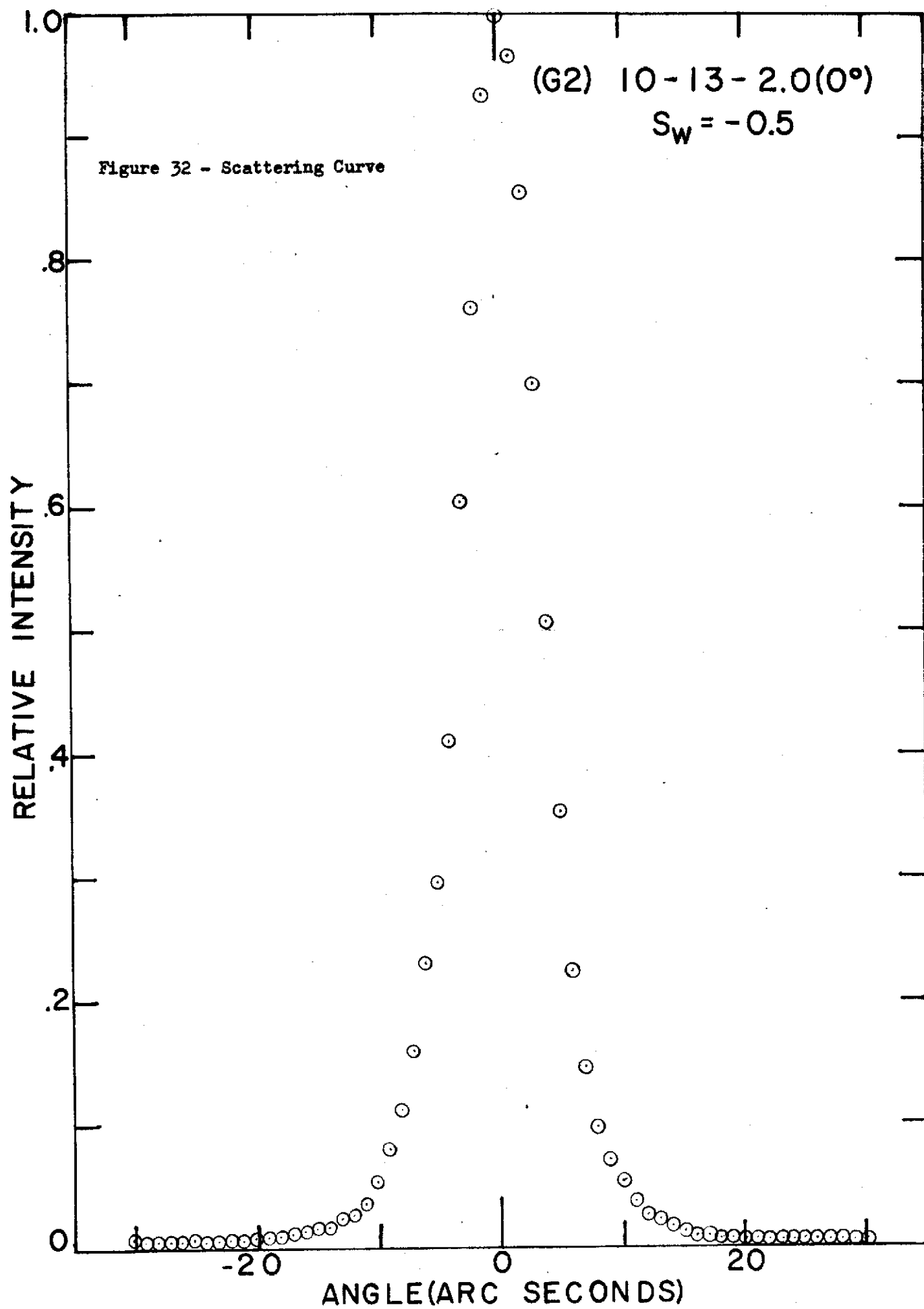


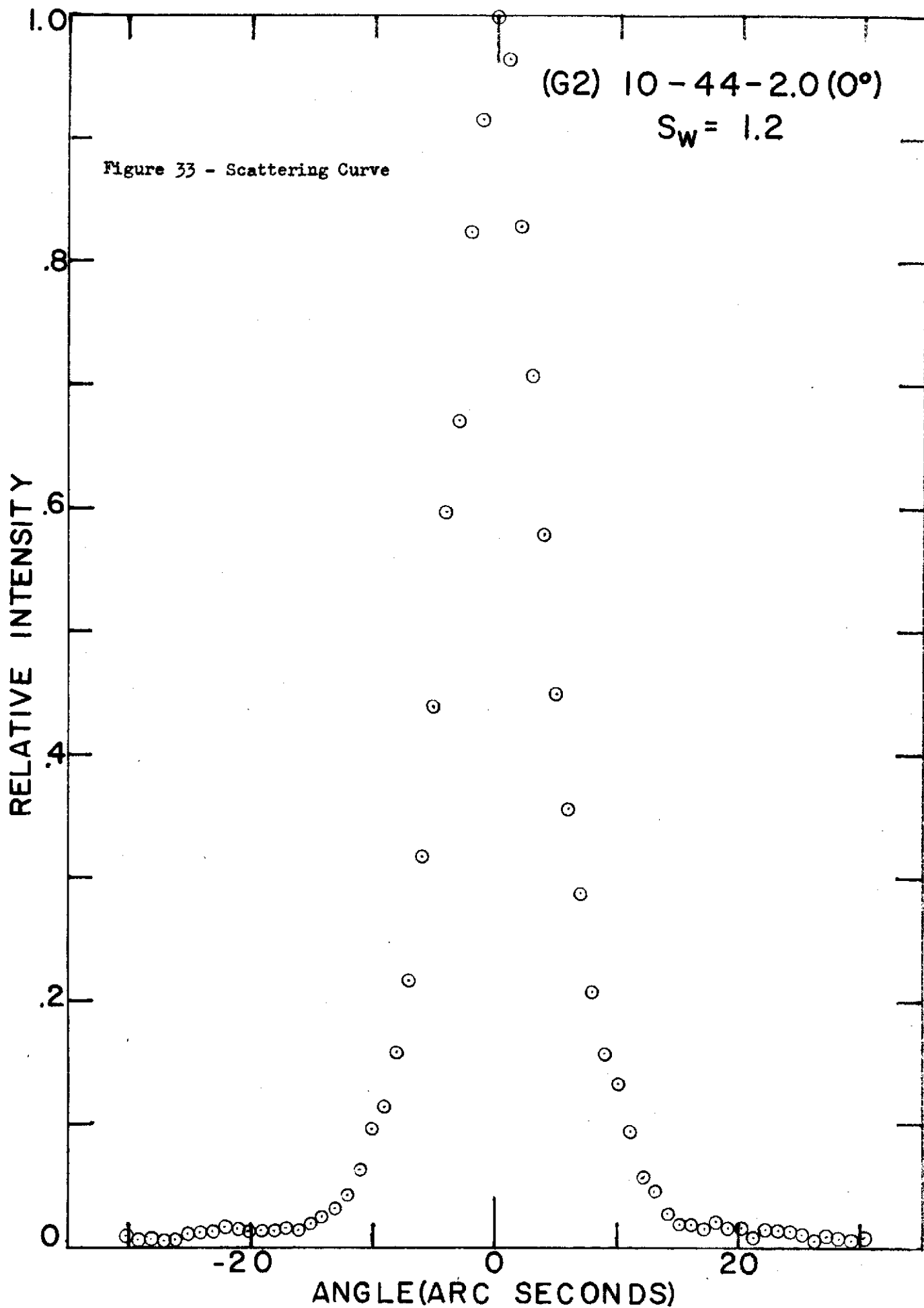


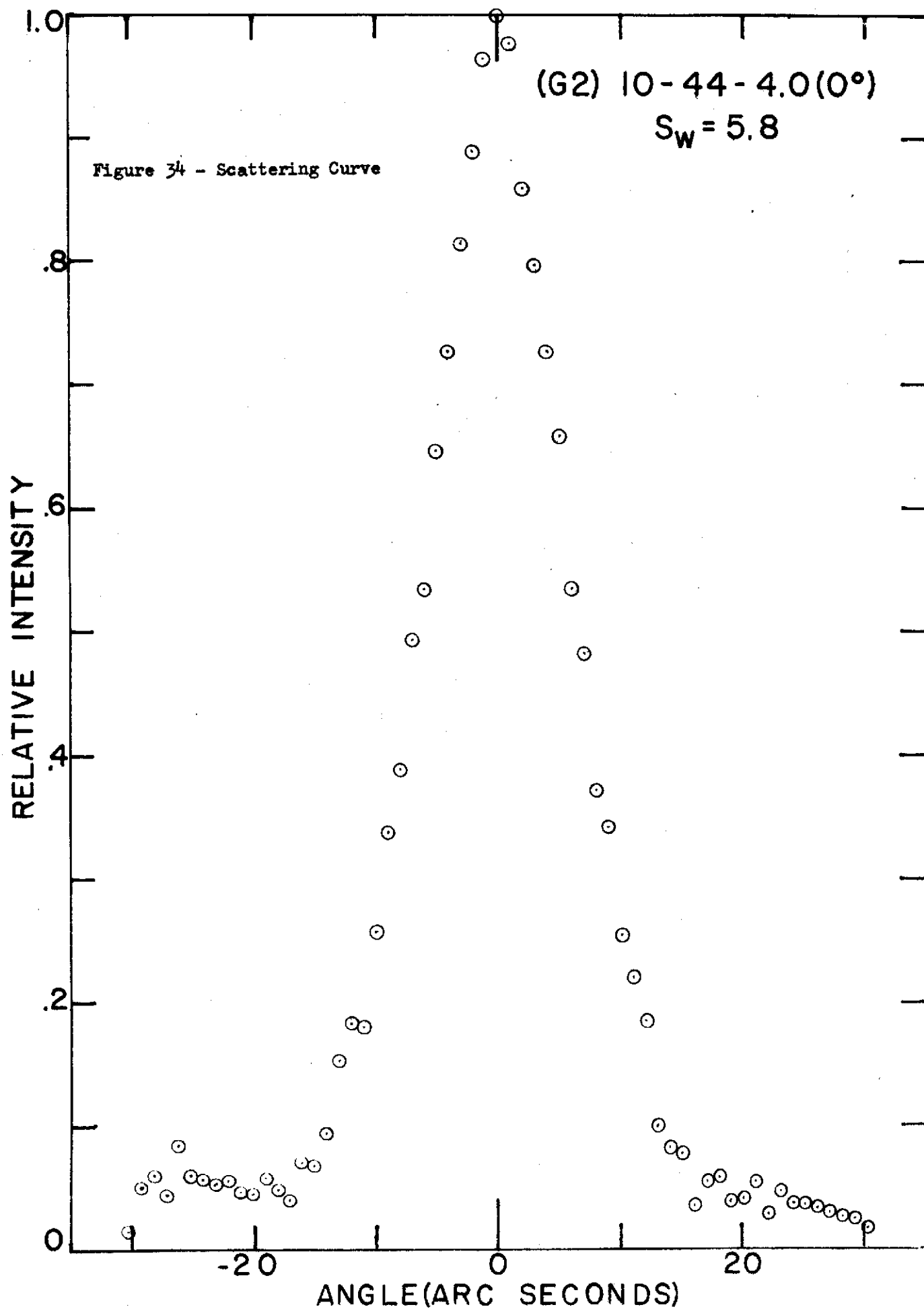


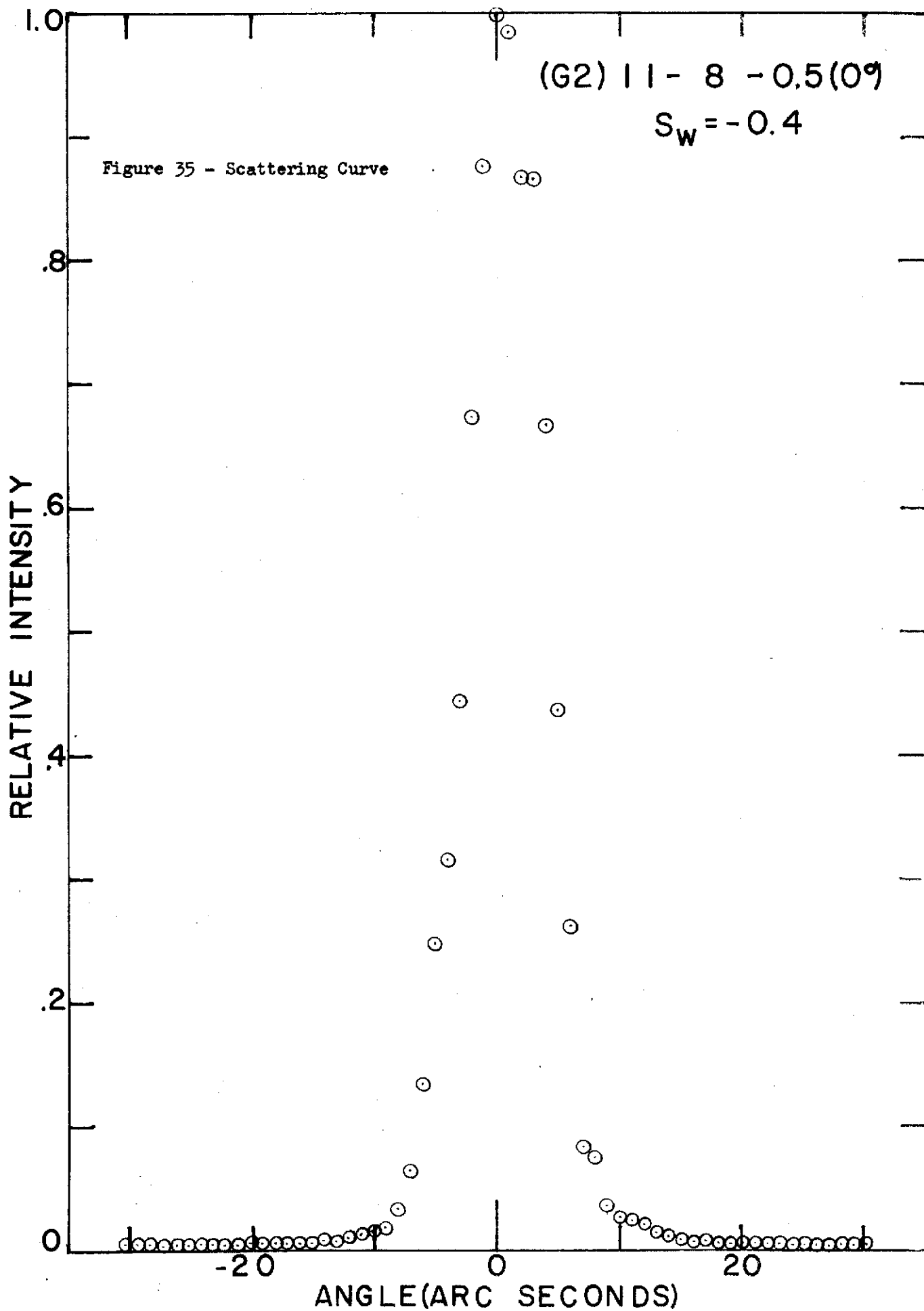


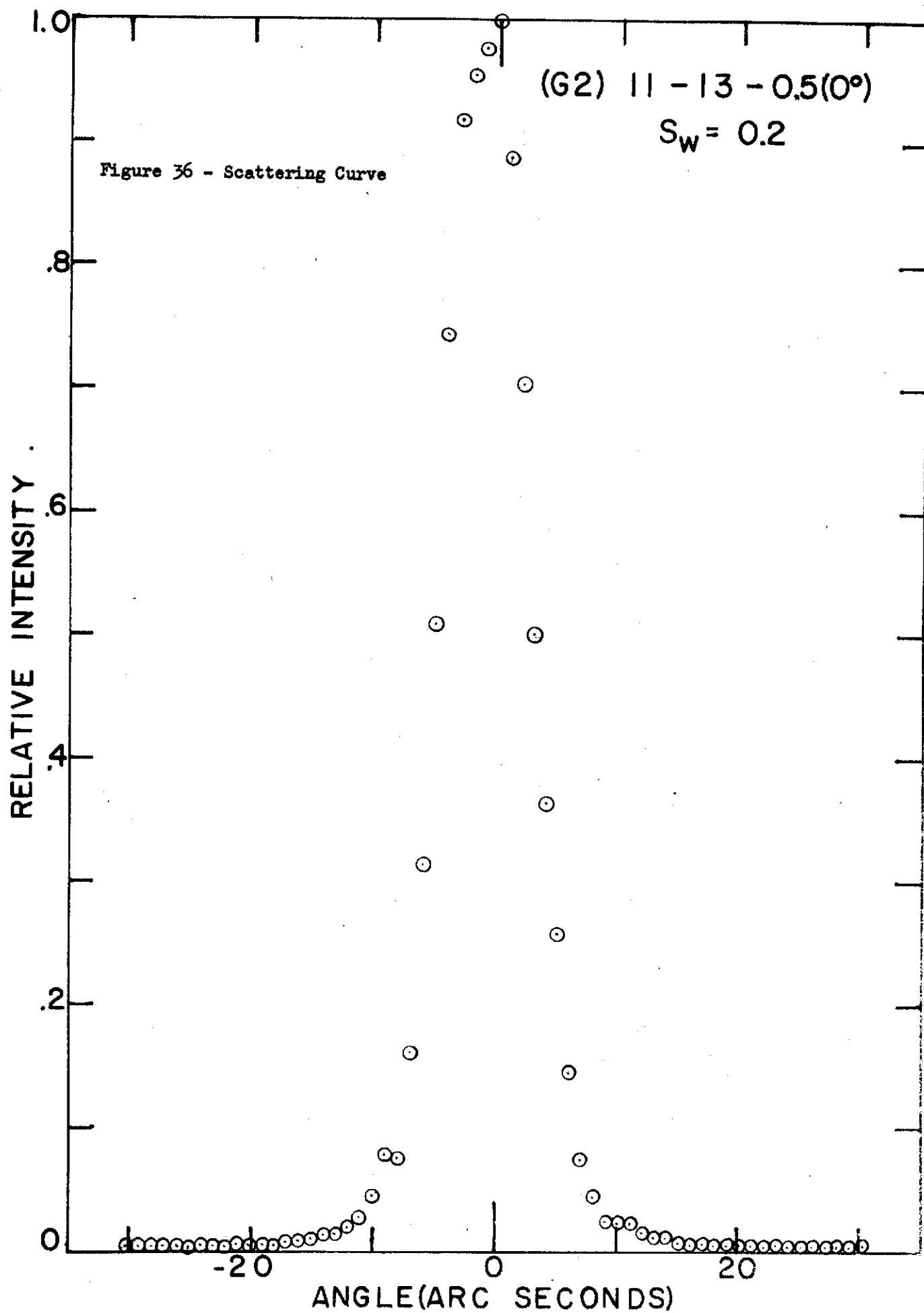


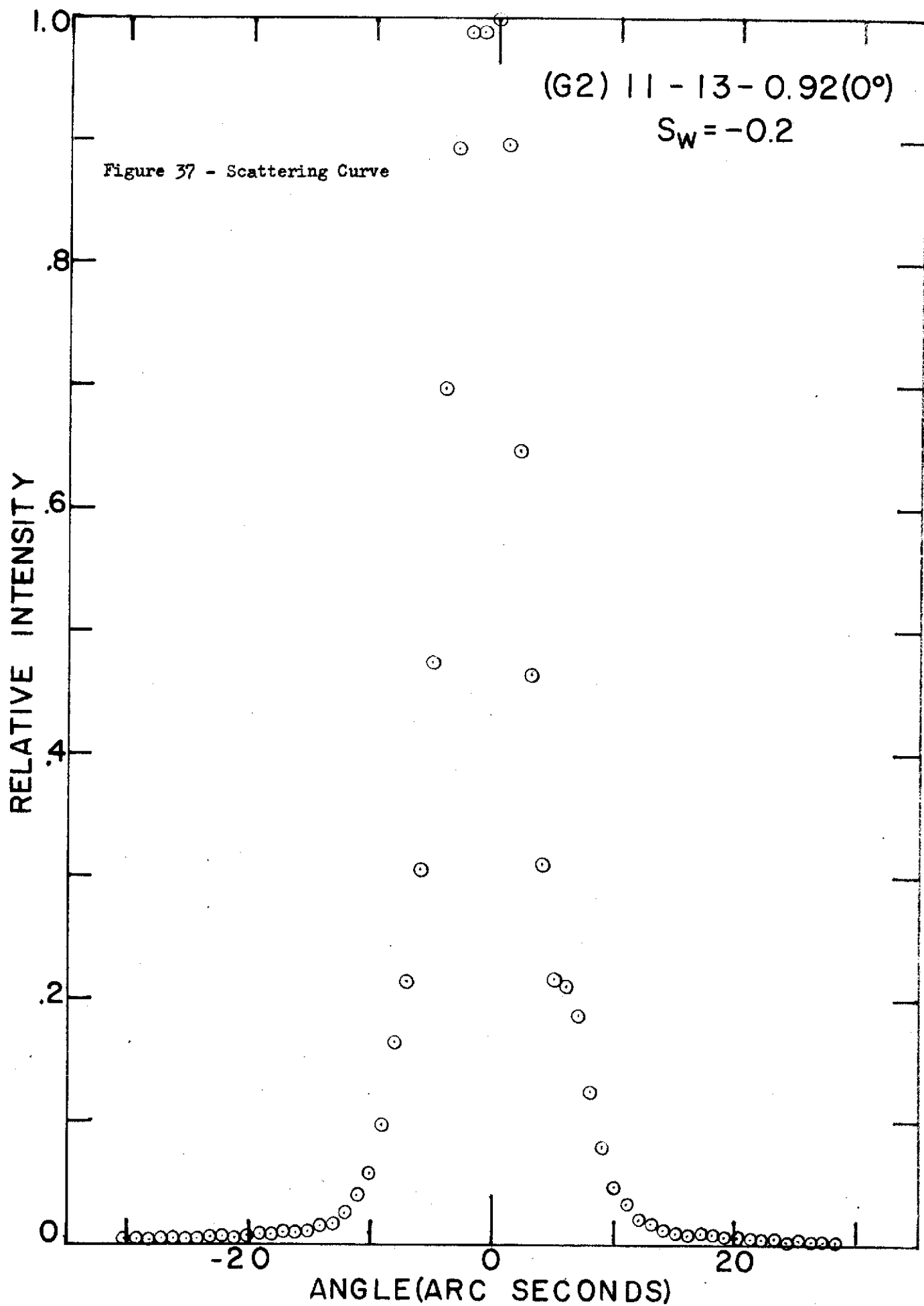


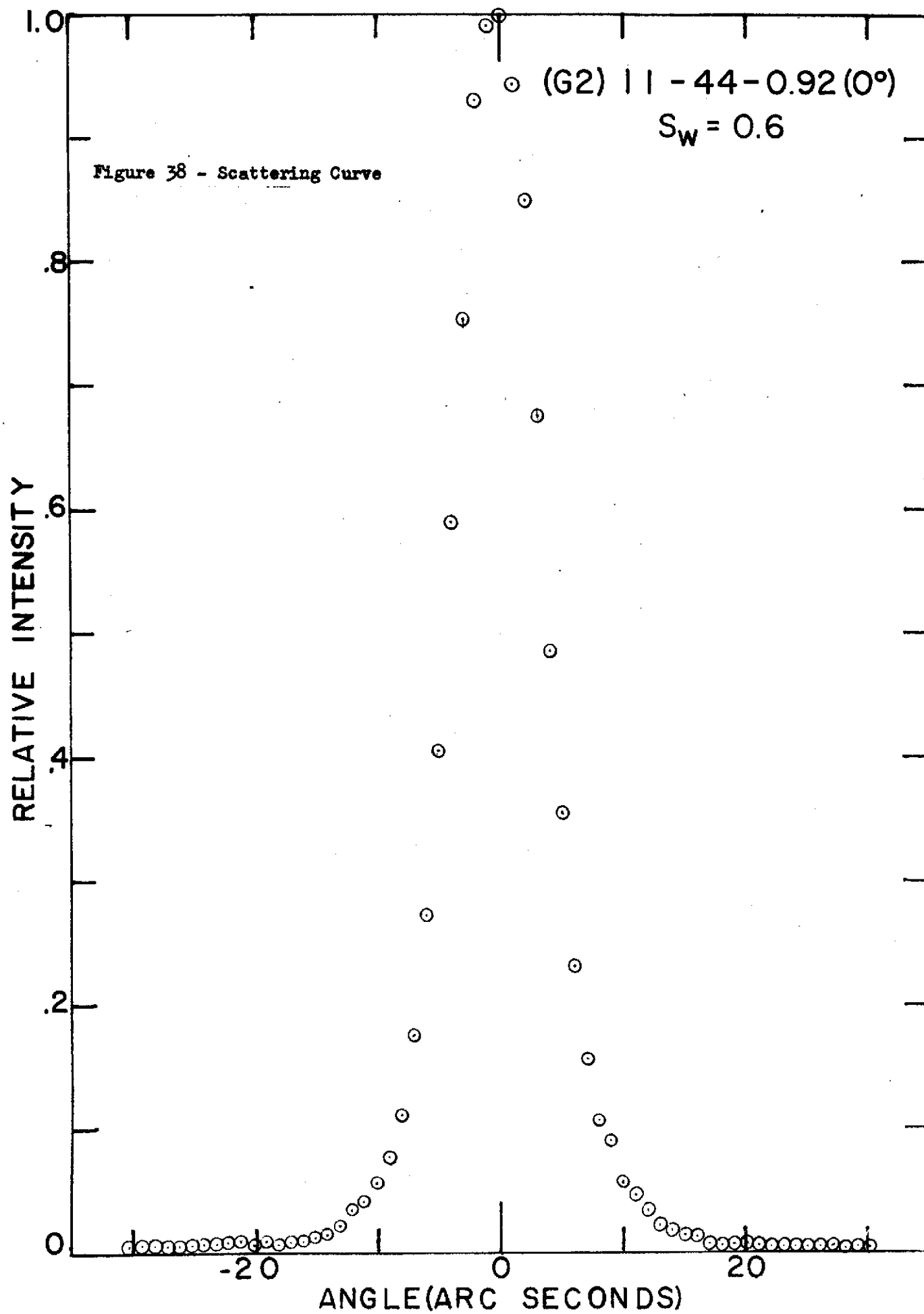


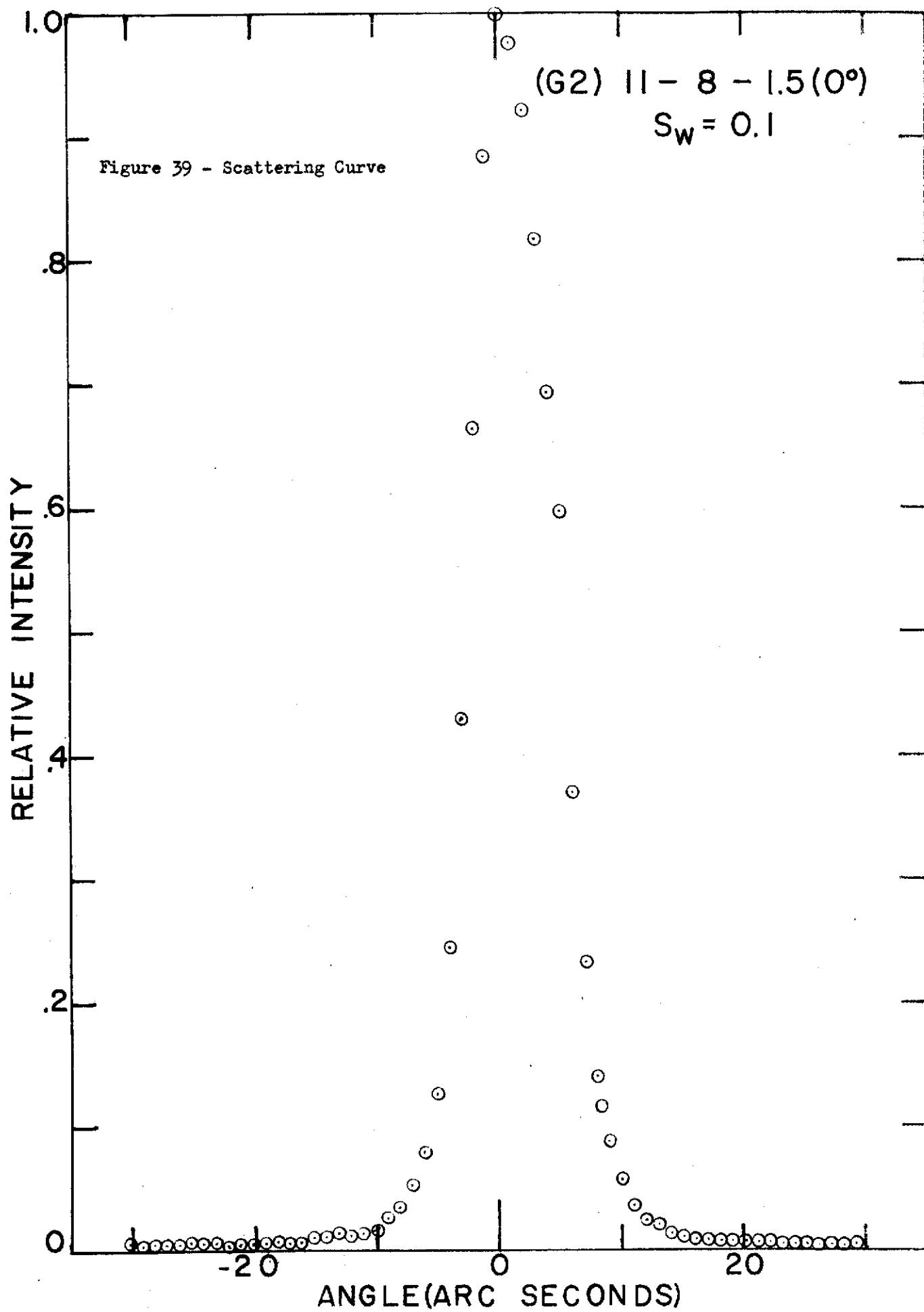


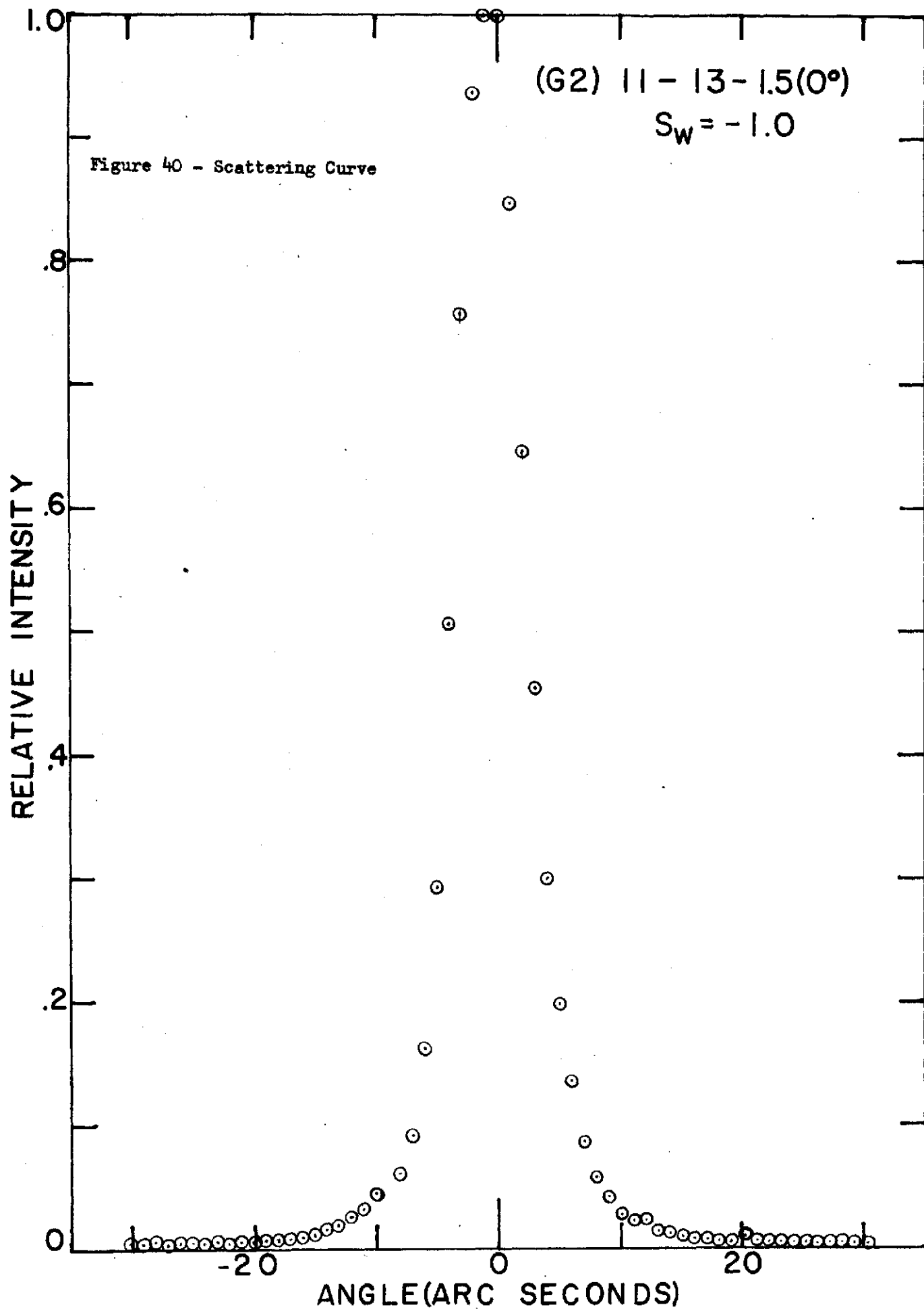


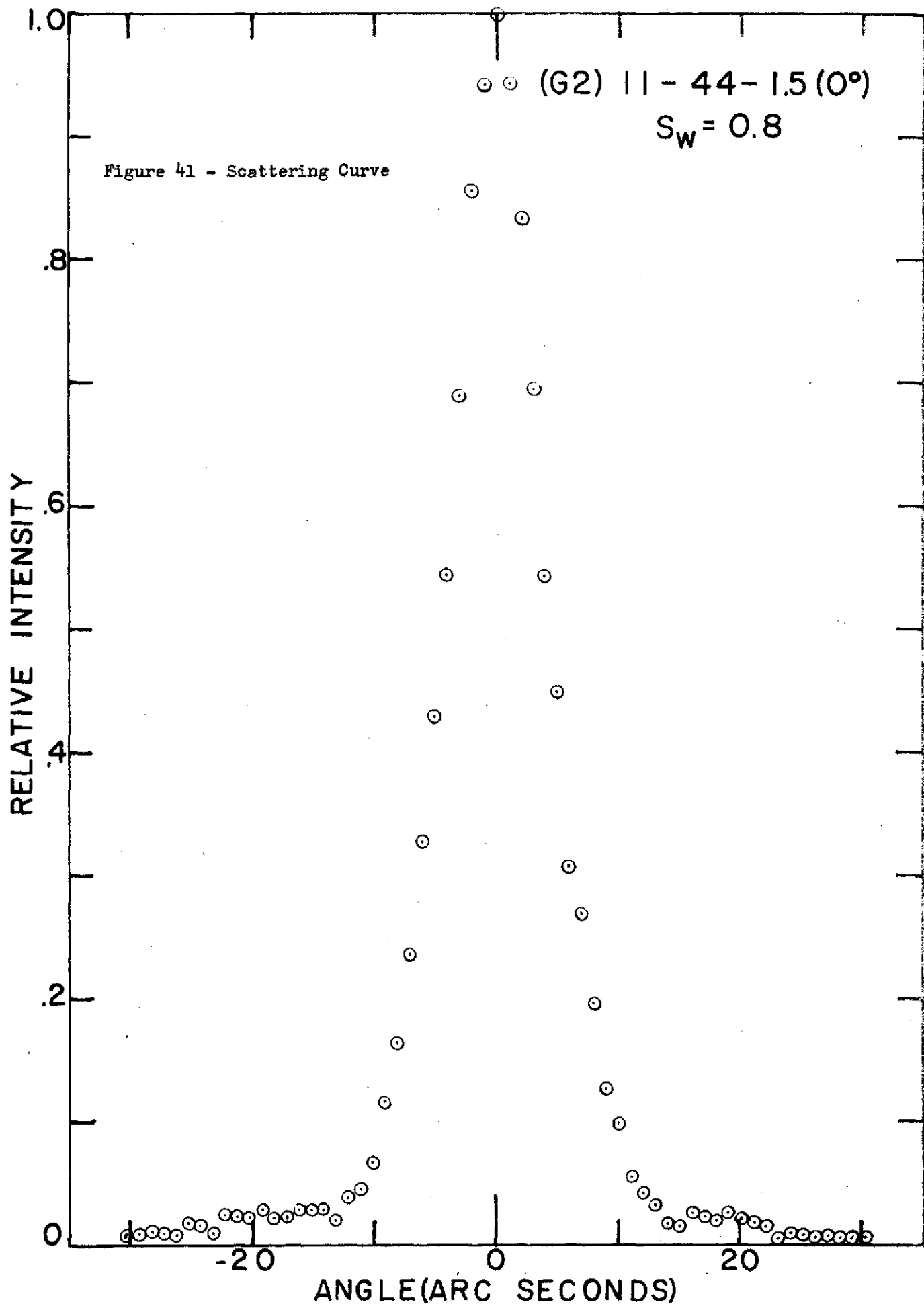


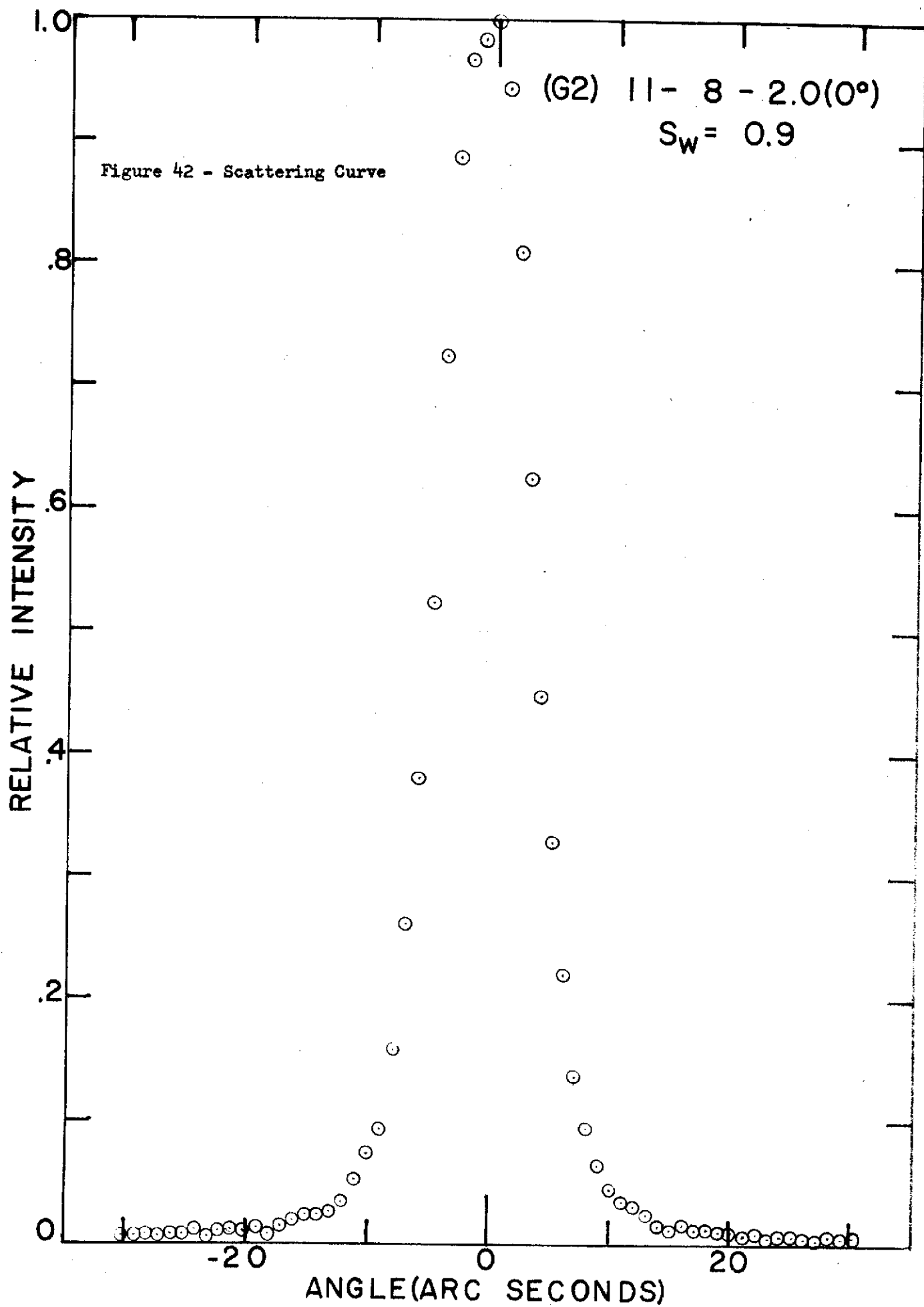


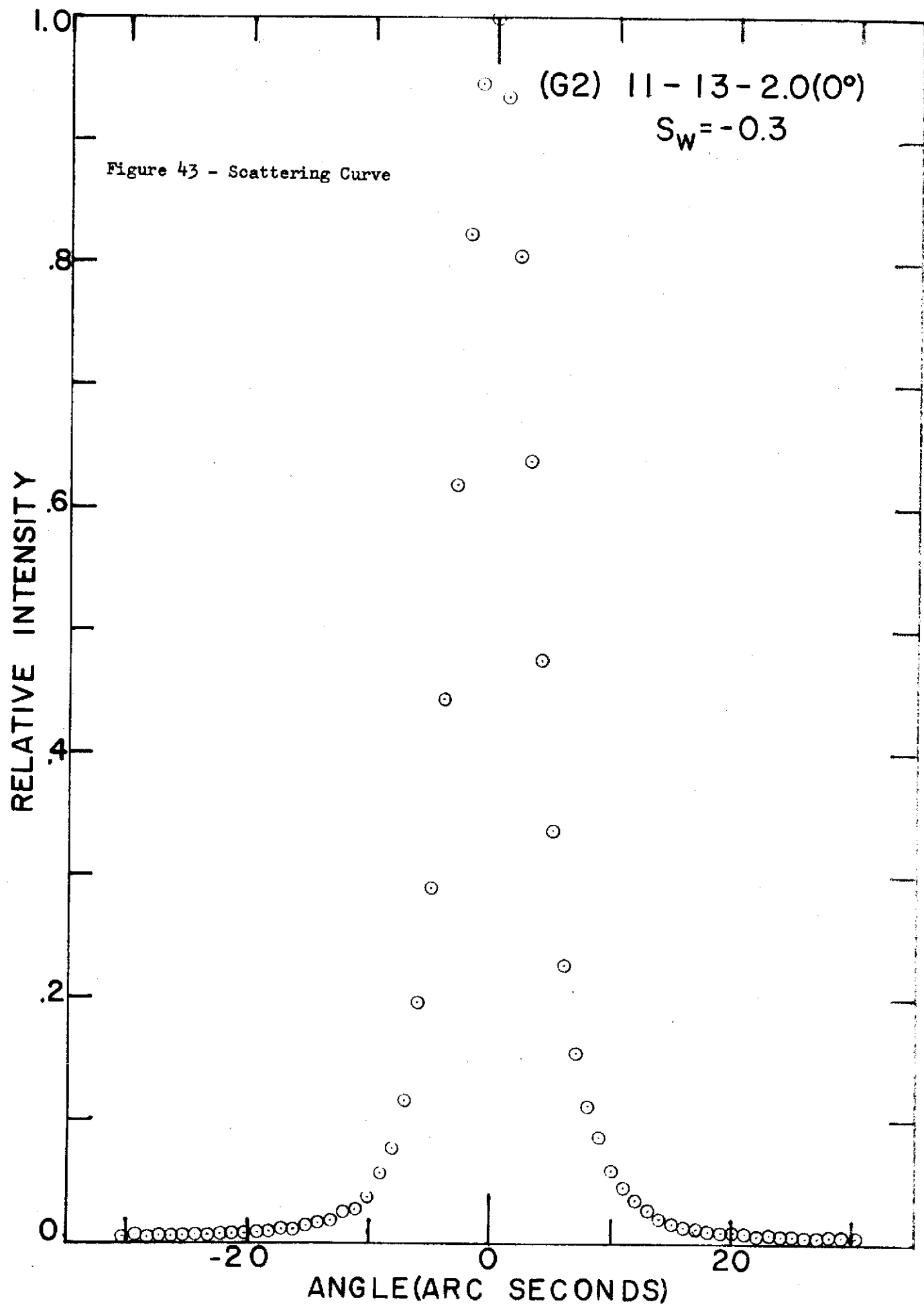


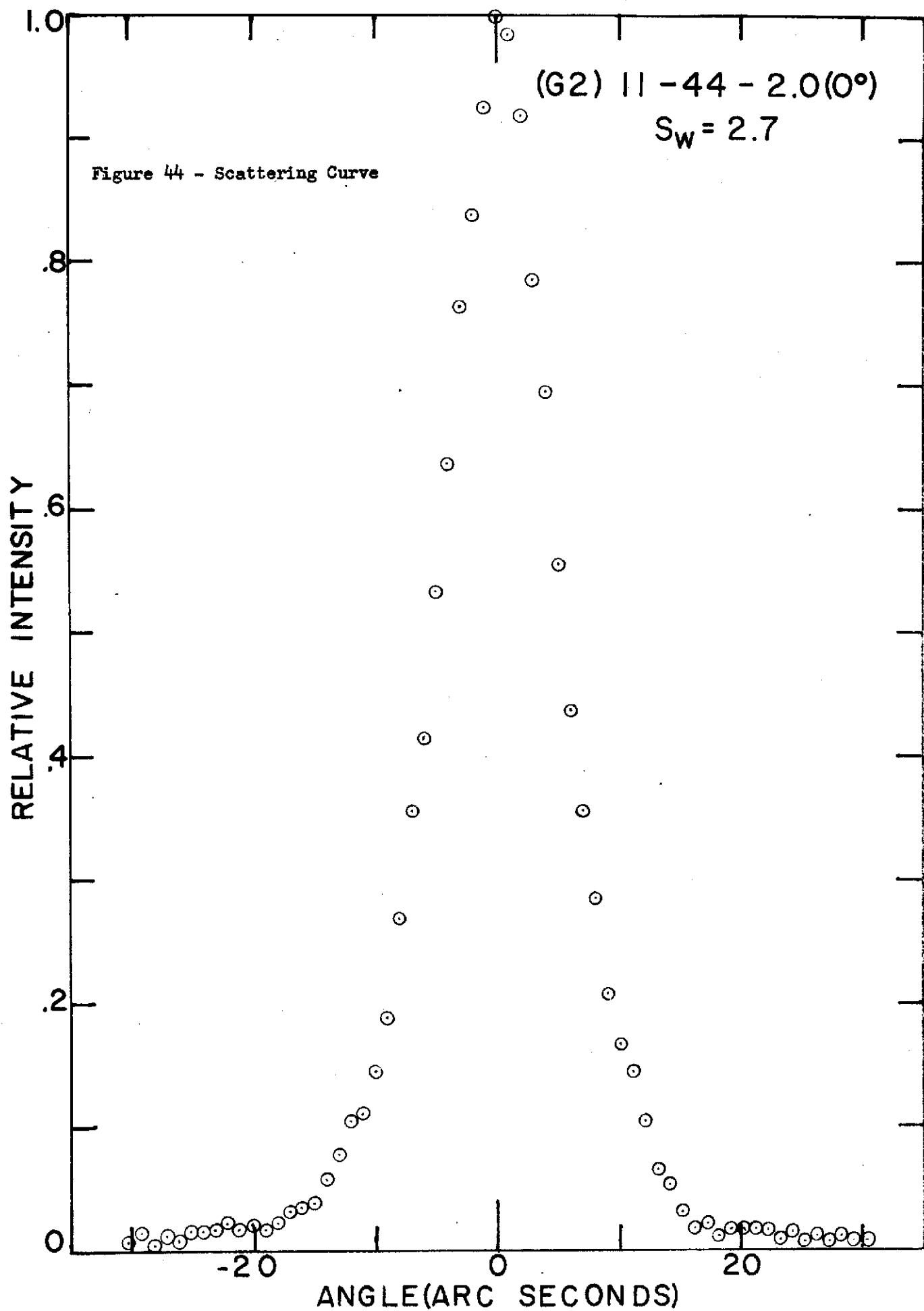


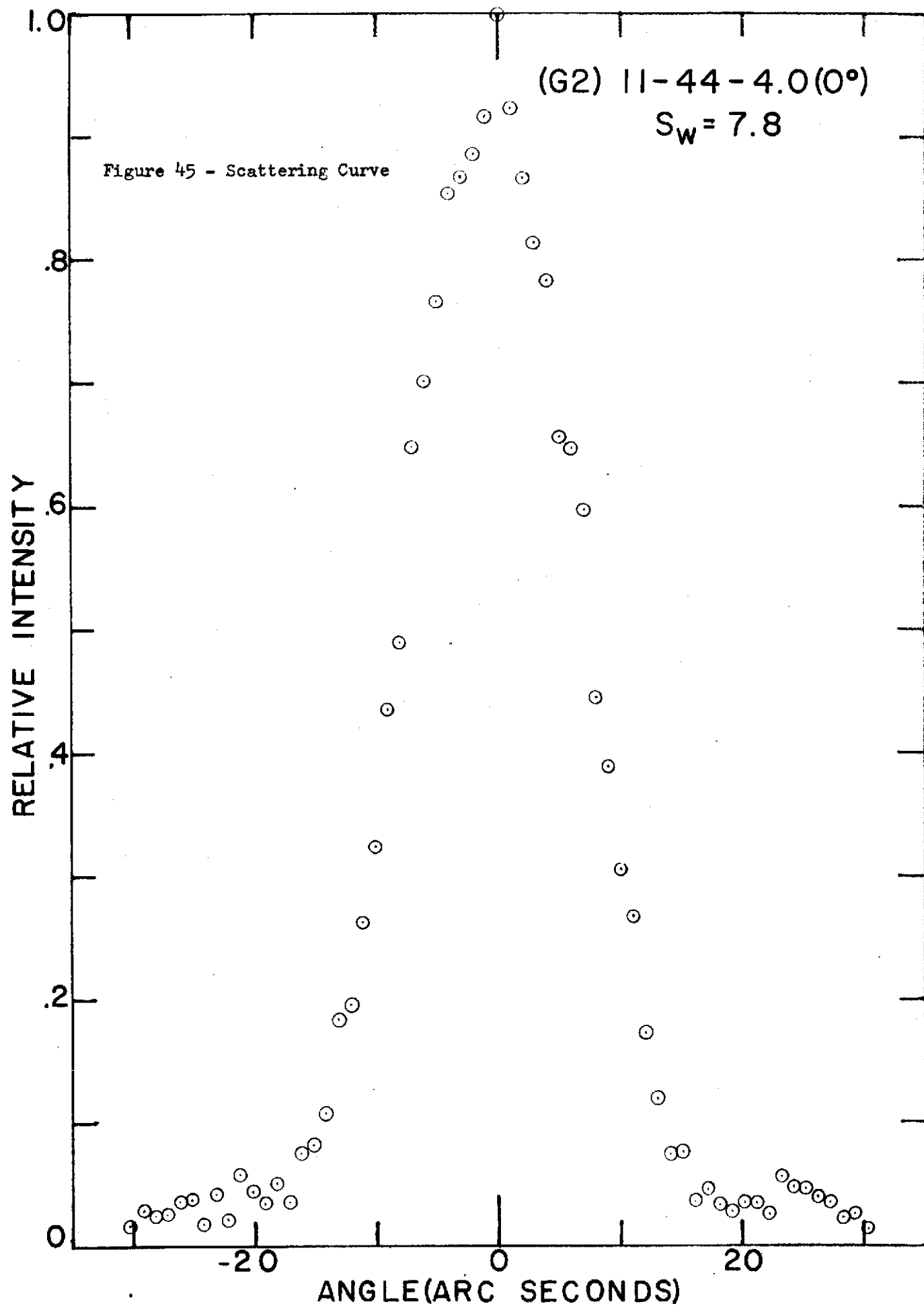












Angle (Arc Sec)		-30	-20	-10	-5	0	5	10	20	30
Wavelength (Å)	Incidence Angle (Deg)	Relative Intensity								
8.3	0.5	.003	.009	.046	.345	1.000	.336	.063	.009	.003
	1.5	.003	.004	.062	.533	1.000	.371	.038	.003	.002
	2.0	.003	.010	.086	.433	1.000	.488	.106	.012	.006
13.3	0.5	.006	.011	.029	.193	1.000	.345	.086	.013	.007
	0.92	.002	.004	.041	.382	1.000	.392	.041	.007	.003
	1.5	.002	.005	.039	.267	1.000	.219	.028	.006	.003
	2.0	.002	.005	.055	.447	1.000	.404	.047	.006	.003
44.0	0.92	.005	.008	.033	.251	1.000	.414	.073	.012	.008
	1.50	.005	.017	.139	.519	1.000	.446	.110	.024	.027
	2.0	.015	.023	.101	.402	1.000	.728	.310	.027	.014
	4.0	.027	.036	.345	.860	1.000	.748	.184	.029	.016

TABLE 1. Phase II, Nine Point Data, Sample 2, 0° Rotation

Angle (Arc Sec)		-30	-20	-10	-5	0	5	10	20	30
Wavelength (Å)	Incidence Angle (Deg)	Relative Intensity								
8.3	0.5	.003	.006	.023	.387	1.000	.233	.024	.005	.003
	1.5	.002	.005	.036	.282	1.000	.446	.049	.005	.004
	2.0	.001	.009	.044	.396	1.000	.307	.046	.020	.006
13.3	0.5	.003	.006	.030	.316	1.000	.280	.032	.009	.005
	0.92	.000	.006	.068	.304	1.000	.449	.050	.005	.000
	1.5	.003	.008	.043	.376	1.000	.358	.049	.006	.002
	2.0	.008	.016	.165	.558	1.000	.584	.137	.022	.006
44.0	0.92	.007	.008	.035	.488	1.000	.174	.022	.007	.005
	1.50	.007	.013	.050	.334	1.000	.393	.077	.015	.004
	2.0	.006	.013	.135	.415	1.000	.562	.123	.015	.003
	4.0	.021	.028	.221	.580	1.000	.709	.282	.037	.024

TABLE 2. Phase II, Nine Point Data, Sample 7, 0° Rotation

Angle (Arc Sec)		-30	-20	-10	-5	0	5	10	20	30
Wavelength (Å)	Incidence Angle (Deg)	Relative Intensity								
8.3	0.5	.006	.008	.039	.359	1.000	.164	.035	.011	.007
	1.5	.005	.009	.057	.370	1.000	.322	.044	.008	.005
	2.0	.008	.009	.035	.271	1.000	.397	.056	.014	.008
13.3	0.5	.004	.010	.038	.341	1.000	.480	.072	.015	.006
	0.92	.004	.008	.037	.303	1.000	.354	.048	.007	.005
	1.5	.005	.006	.031	.287	1.000	.233	.034	.007	.004
	2.0	.004	.006	.053	.352	1.000	.296	.053	.009	.005
44.0	0.92	.006	.006	.055	.351	1.000	.270	.042	.011	.004
	1.5	.008	.014	.084	.588	1.000	.408	.077	.015	.004
	2.0	.009	.016	.131	.451	1.000	.440	.098	.014	.009
	4.0	.017	.040	.253	.659	1.000	.648	.258	.043	.014

TABLE 3. Phase II, Nine Point Data, Sample 10, 0° Rotation

Angle (Arc Sec)		-30	-20	-10	-5	0	5	10	20	30
Wavelength (Å)	Incidence Angle (Deg)	Relative Intensity								
8.3	0.5	.003	.005	.028	.438	1.000	.250	.016	.005	.003
	1.5	.001	.007	.058	.598	1.000	.127	.017	.005	.004
	2.0	.005	.010	.045	.328	1.000	.522	.074	.010	.006
13.3	0.5	.003	.007	.024	.260	1.000	.510	.047	.005	.003
	0.92	.002	.008	.125	.468	1.000	.216	.023	.005	.002
	1.5	.003	.005	.042	.300	1.000	.162	.028	.005	.002
	2.0	.003	.008	.060	.336	1.000	.289	.037	.006	.003
44.0	0.92	.004	.009	.058	.355	1.000	.407	.058	.008	.006
	1.50	.007	.021	.099	.449	1.000	.429	.067	.022	.008
	2.0	.015	.024	.172	.557	1.000	.535	.177	.025	.013
	4.0	.014	.036	.304	.671	1.000	.779	.325	.043	.016

TABLE 4. Phase II, Nine Point Data, Sample 11, 0° Rotation

This then is another number which can be used as an index of sample performance in comparisons. These values of percent scattered are tabulated in Table 5. The percent scattered values represent an intensity that must come only from scattered radiation. They provide a calculation method which is objective and does not depend on experimental uncertainties in slit width. The method of adding the area under the curve is subject to large uncertainties because of possible slit width errors.

REFLECTING EFFICIENCY MEASUREMENTS

The "efficiency factor", see Table 7, is not an attempt at measuring reflecting efficiency, but rather is used to normalize the data against fluctuations in source intensity. The secondary detector records an intensity (not flux) simultaneously with that obtained in the primary detector. The values recorded will vary as the source output varies, but their ratio will not vary (neglecting counting statistics). Thus, the shape of the curves is not influenced by fluctuations in the source intensity, but the absolute reflecting efficiency is not measured. The efficiency factor used in this report is defined as the ratio of the intensity recorded by the primary detector at the peak of the reflected intensity curves to the secondary or monitor detector intensity. The secondary detector uses a 1/4 inch diameter window of 1/4 mil Mylar. This number can be used to give some insight into the

location of critical angles in reflecting efficiency.

STATISTICAL CONSIDERATIONS

There was no statistical requirement with respect to intensity in the case of the 61 point scattering curves. The time interval was fixed at 100 seconds, and the number of counts collected in this period was used.

The nine points data were taken so that the number of counts at the peak was greater than 10,000 for at least one angle of incidence. These times ranged from 100 seconds to 200 seconds.

Sample No.		2	7	10	11
Incidence					
Angle	Wavelength				
(Deg)	(Å)				
0.5	8.3	1.31	0.99	1.99	0.89
	13.3	2.20	1.35	1.76	0.99
0.92	8.3	0.69	1.00	0.83	0.64
	13.3	0.91	0.54	1.33	0.89
	44.0	1.86	1.56	1.58	1.35
1.5	8.3	0.62	0.91	1.44	0.94
	13.3	1.00	0.97	1.37	1.01
	44.0	3.22	2.12	1.90	2.78
2.0	8.3	1.44	1.97	2.23	1.55
	13.3	0.83	2.07	1.34	1.16
	44.0	3.01	1.63	2.21	3.07
4.0	44.0	3.34	3.77	3.87	3.43

TABLE 5. Phase II, 0° Rotation, Percent Scattered (S)

Sample No.		2	7	10	11
Incidence					
Angle	Wavelength				
(Deg)	(Å)				
0.5	8.3	-0.6	0.5	-0.8	-0.4
	13.3	-1.2	-0.9	1.2	0.2
0.92	8.3	-0.6	-0.8	0.4	0.6
	13.3	0.7	0.6	-0.2	-0.2
	44.0	-0.2	-0.7	-1.5	0.6
1.5	8.3	1.2	0.2	0.2	0.1
	13.3	-1.2	0.6	-0.7	-1.0
	44.0	1.6	0.2	0.8	0.8
2.0	8.3	1.3	0.3	0.1	0.9
	13.3	1.0	3.4	-0.5	-0.3
	44.0	3.4	1.7	1.2	2.7
4.0	44.0	6.4	5.5	5.8	7.8

TABLE 6. Phase II, 0° Rotation, Scattering Width (S_w)

Sample No.		2	7	10	11
Incidence Angle (Deg)	Wavelength (Å)				
0.5	8.3	0.00492	0.01176	0.00374	0.01449
	13.3	0.01385	0.00913	0.00848	0.02016
0.92	8.3	0.01230	0.01938	0.01067	0.01144
	13.3	0.06413	0.00694	0.26314	0.01469
	44.0	0.02698	0.01738	0.03916	0.04798
1.5	8.3	0.00488	0.00391	0.00372	0.00304
	13.3	0.02693	0.00816	0.02133	0.01678
	44.0	0.01188	0.01579	0.02366	0.00760
2.0	8.3	0.00165	0.00144	0.00276	0.00110
	13.3	0.00964	0.00813	0.00614	0.00787
	44.0	0.00822	0.00949	0.00876	0.00851
4.0	44.0	0.00248	0.00171	0.00197	0.00216

TABLE 7. Phase II, 0° Rotation, Efficiency Factors (E)

ORIENTATION TESTS

Orientation effects were investigated by measurement of the scattering properties of the four selected polished flats as they were positioned at different angles in the sample holder. Minor defects can be produced during the manufacture, polishing, and/or coating of the polished flats that can cause the samples to have a preferred orientation for the incident x-rays to strike the surface. The positions chosen were 45° , 90° , and 180° about an axis normal to the sample surface, as shown in Figure 46. The orientation was determined for the sample by an arrow on the side of each sample. The orientation tests were done at one wavelength (8.34 \AA) and at one angle of incidence (0.92°).

The scattering measurements were performed following the same procedure as for the wavelength and angular dependence tests previously described in this report.

The scattering curves for the orientation tests are shown in Figures 47 through 58.

The relative intensities for this orientation test are given in Table 8.

Compilations of the scattering widths, percent scattered, and the efficiency factor are given in Table 9.

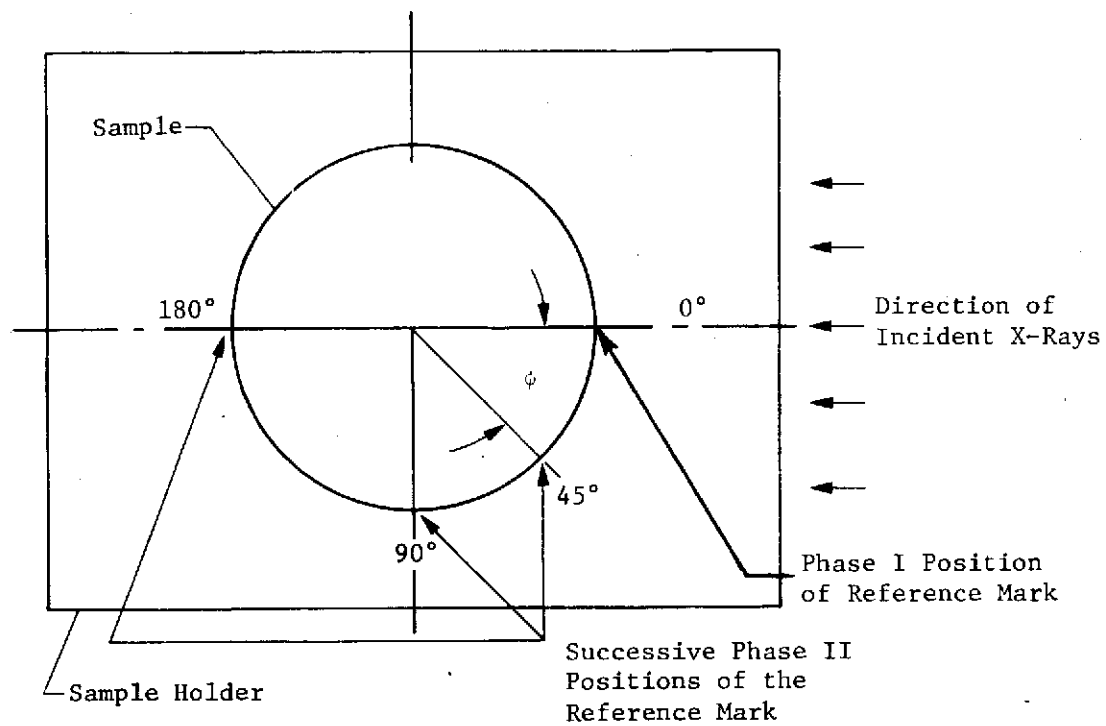
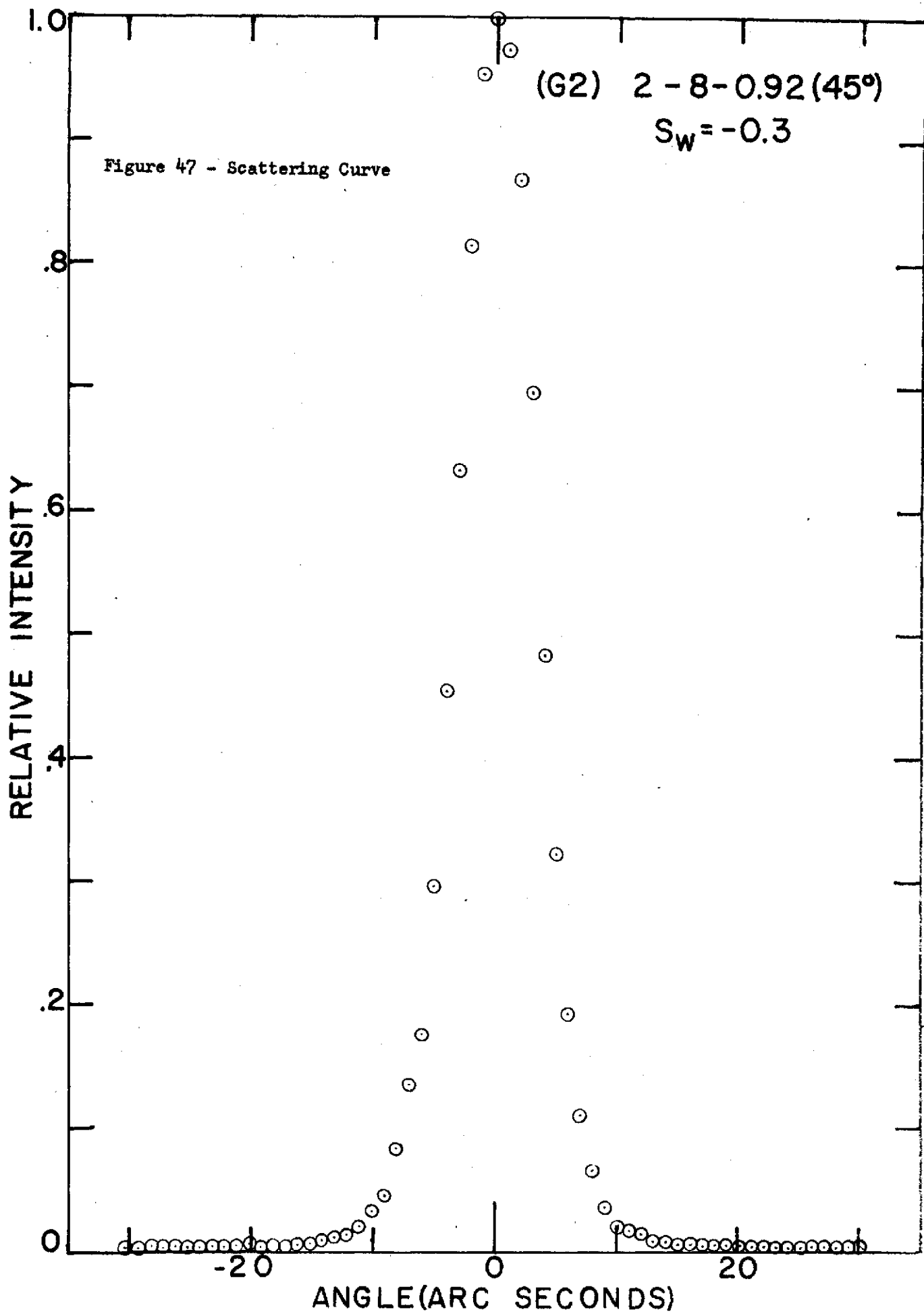
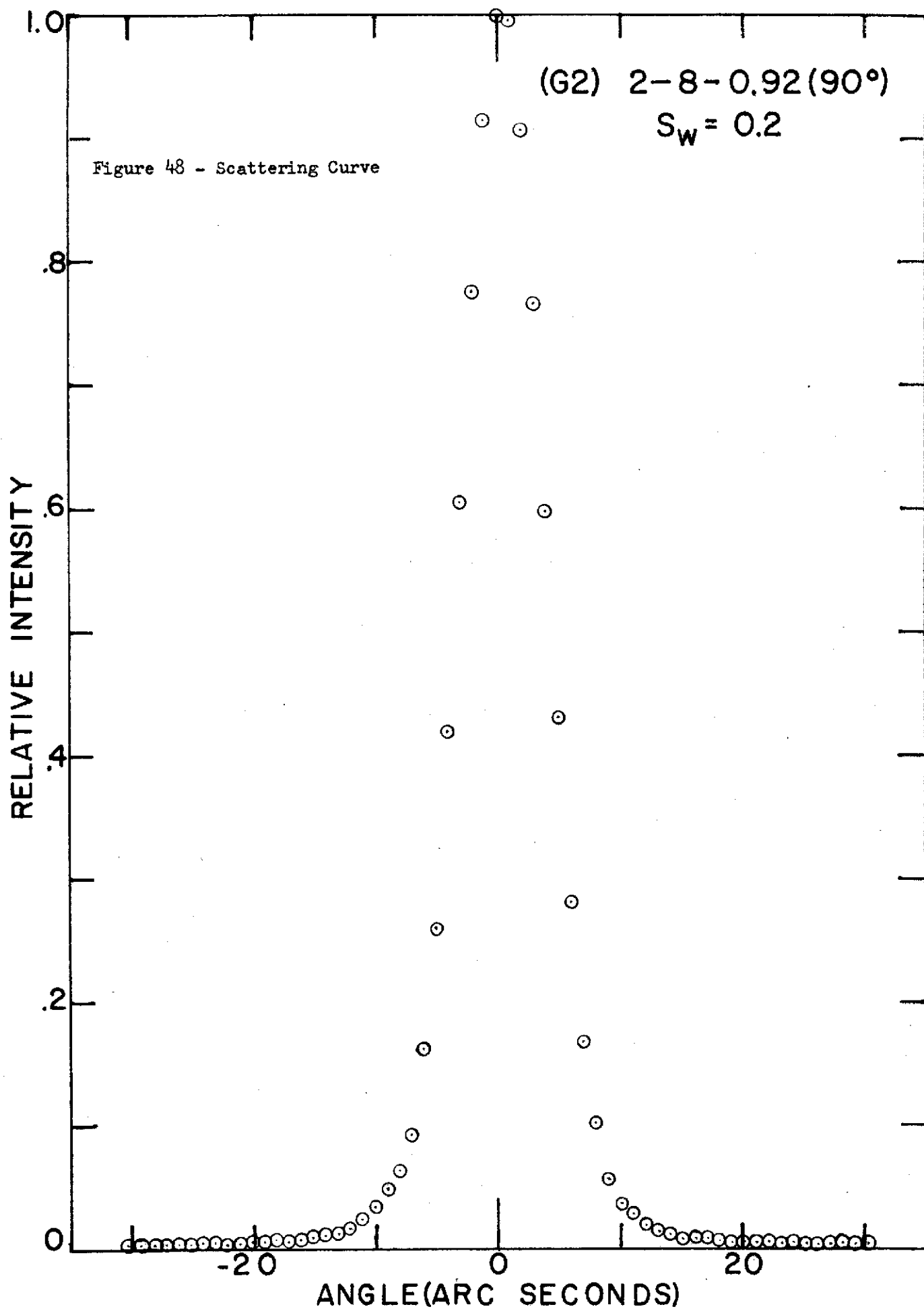
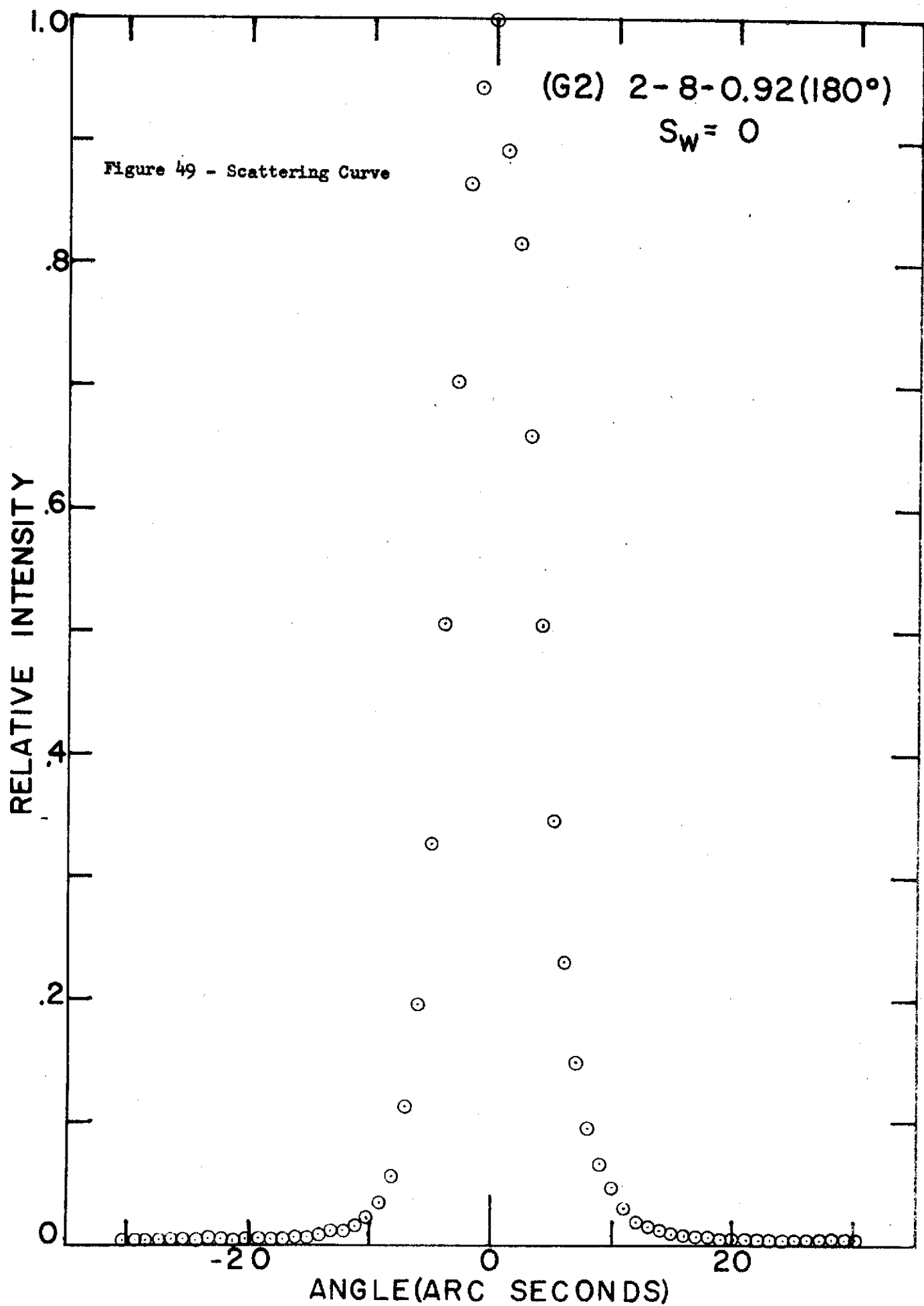
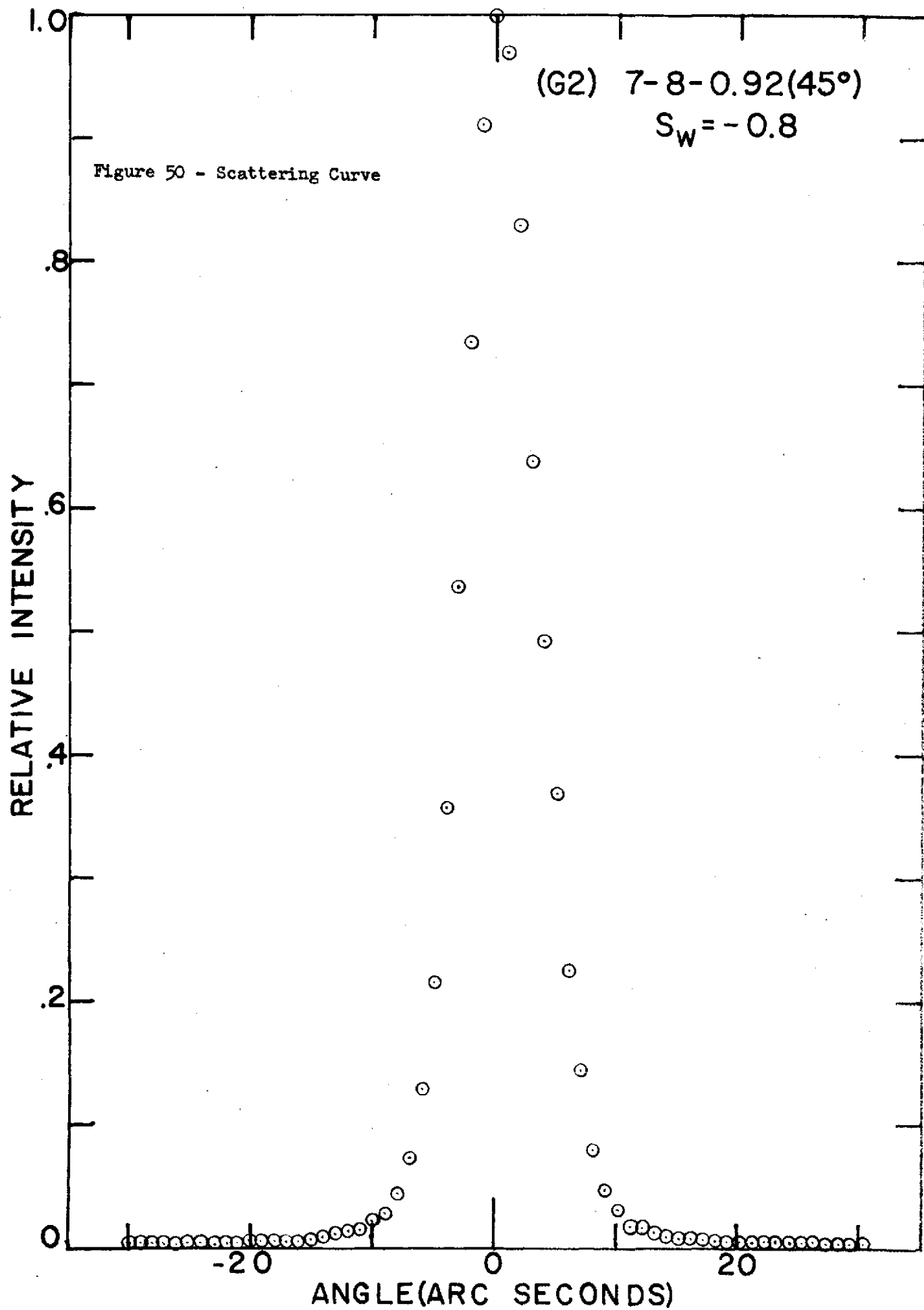


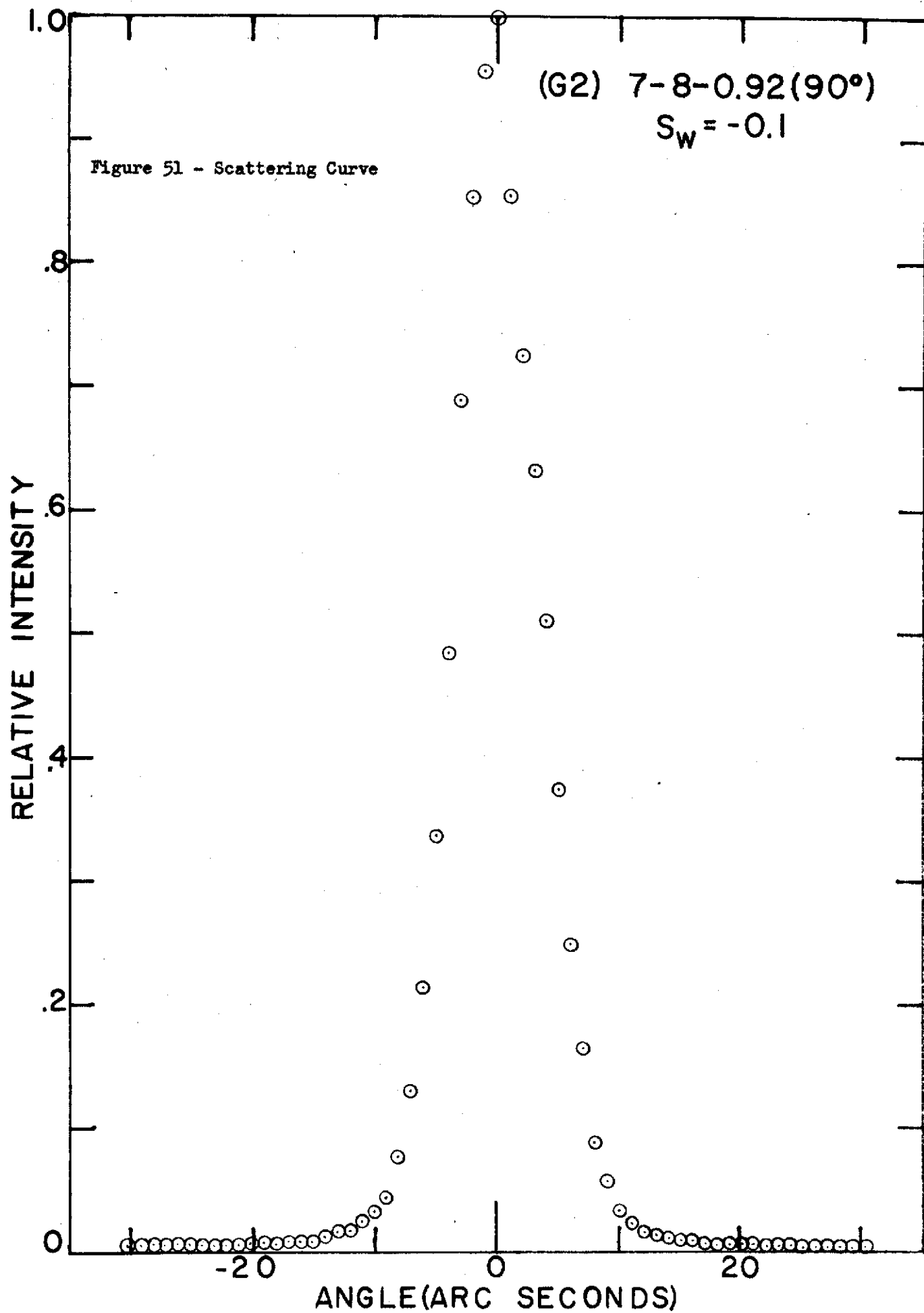
Figure 46 Sample Holder Depicting Sample Rotation

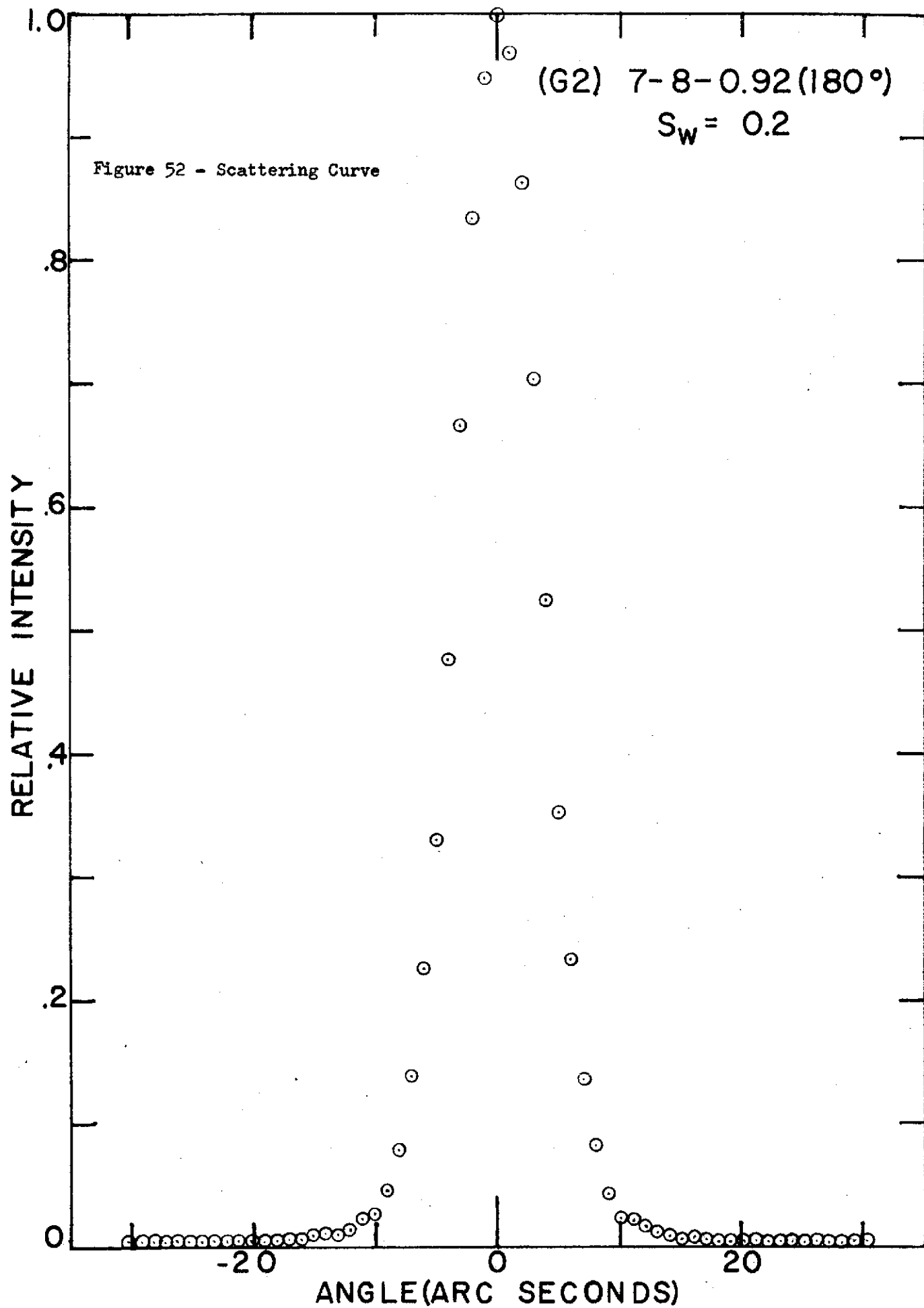


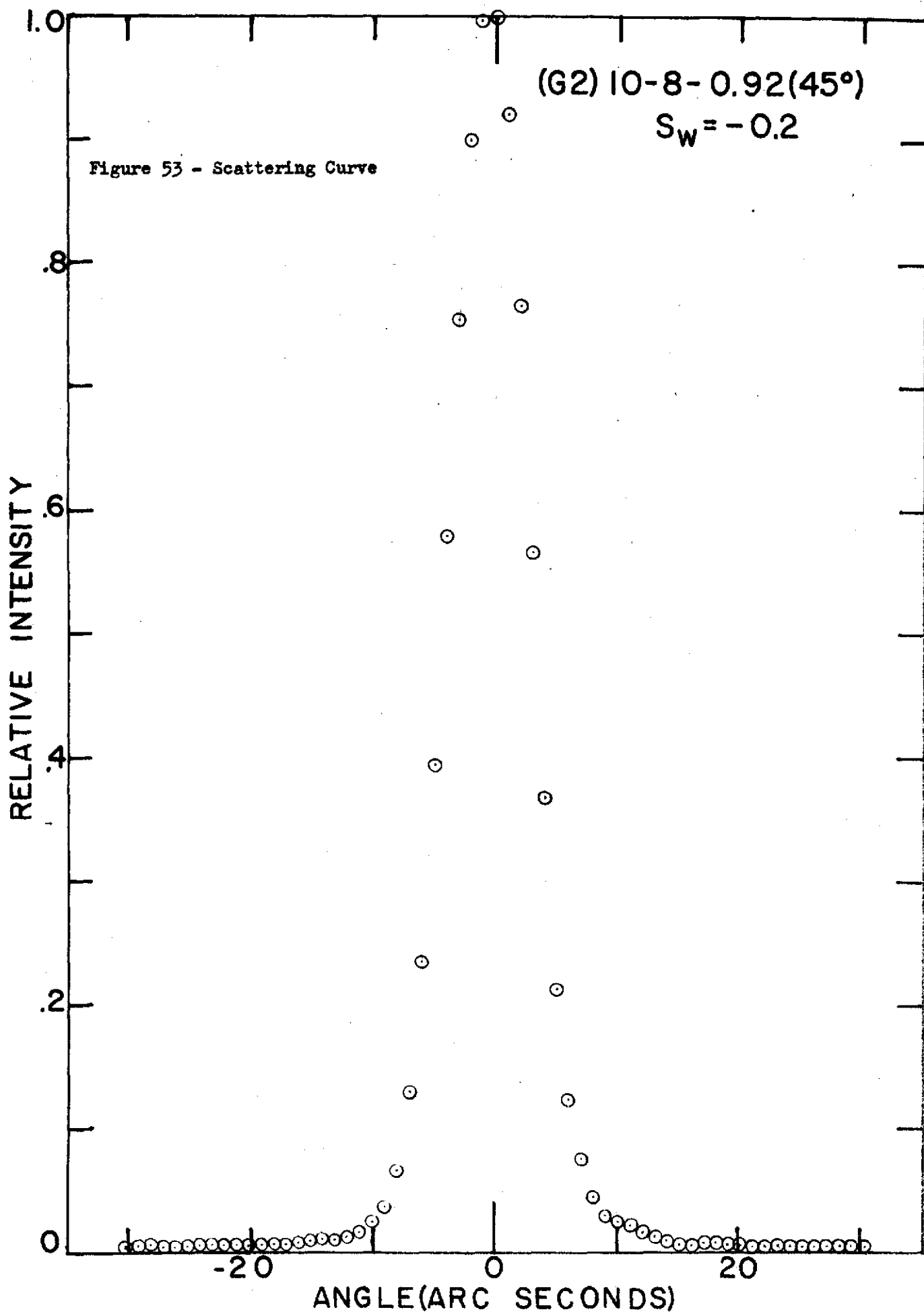


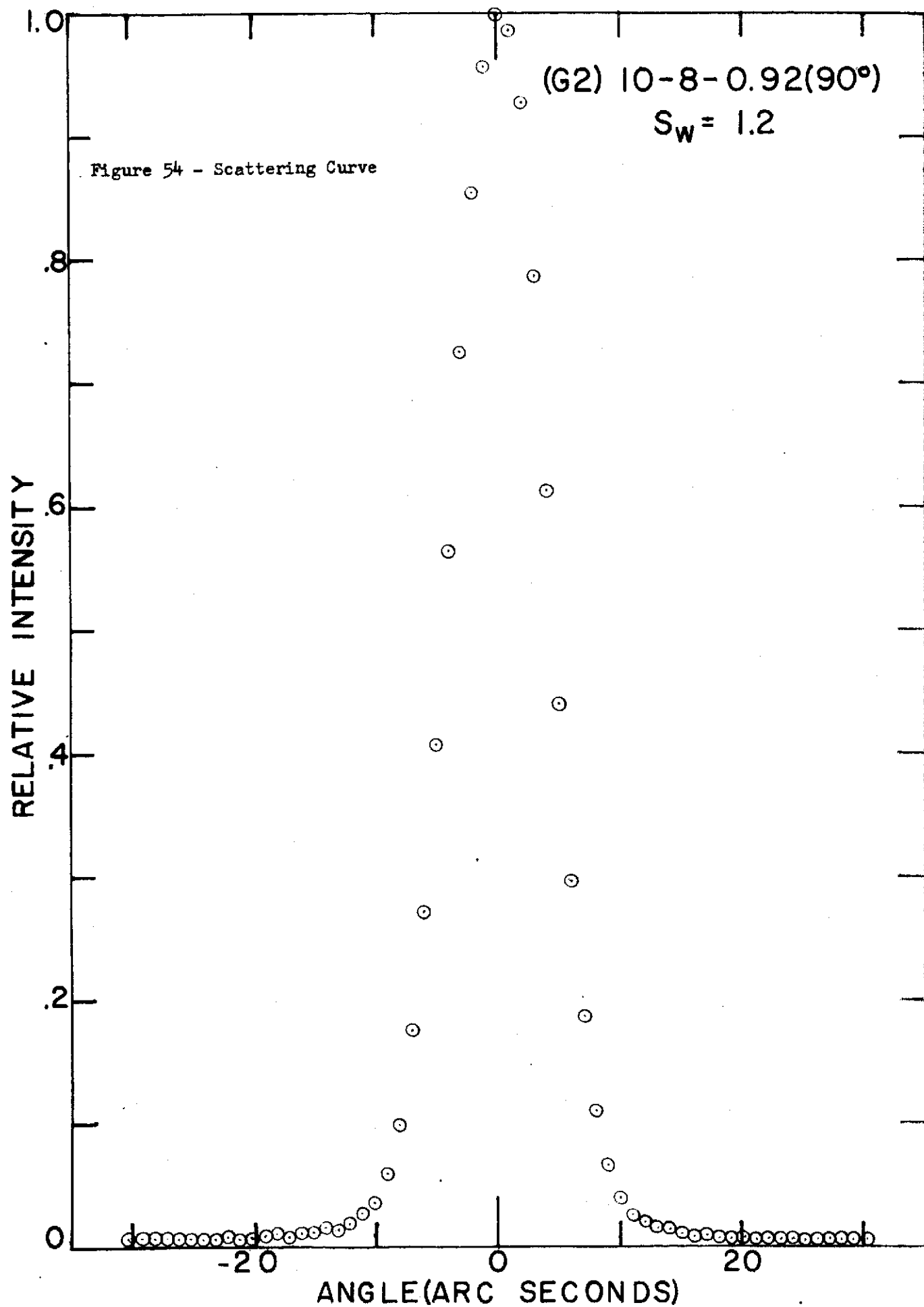


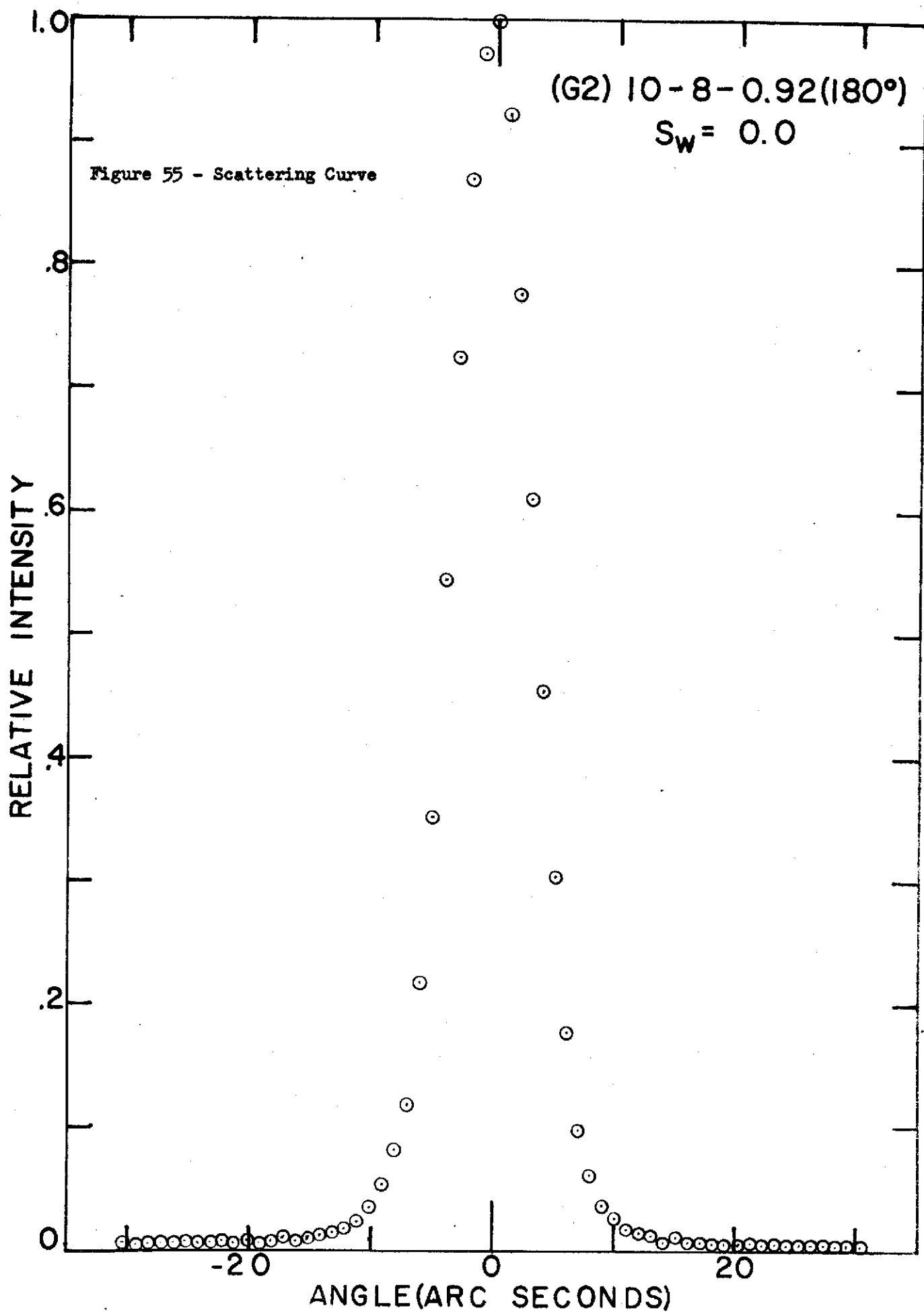


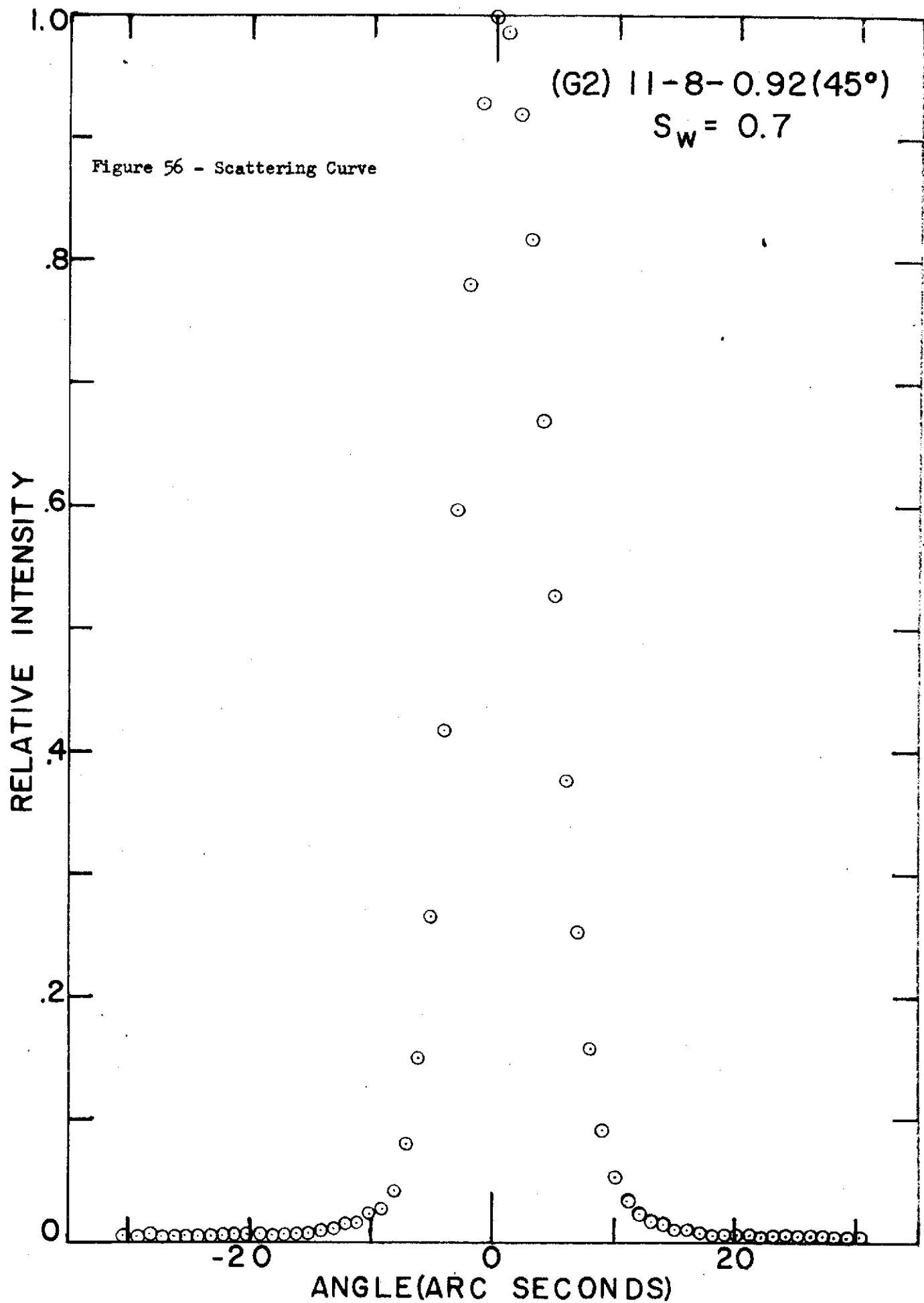


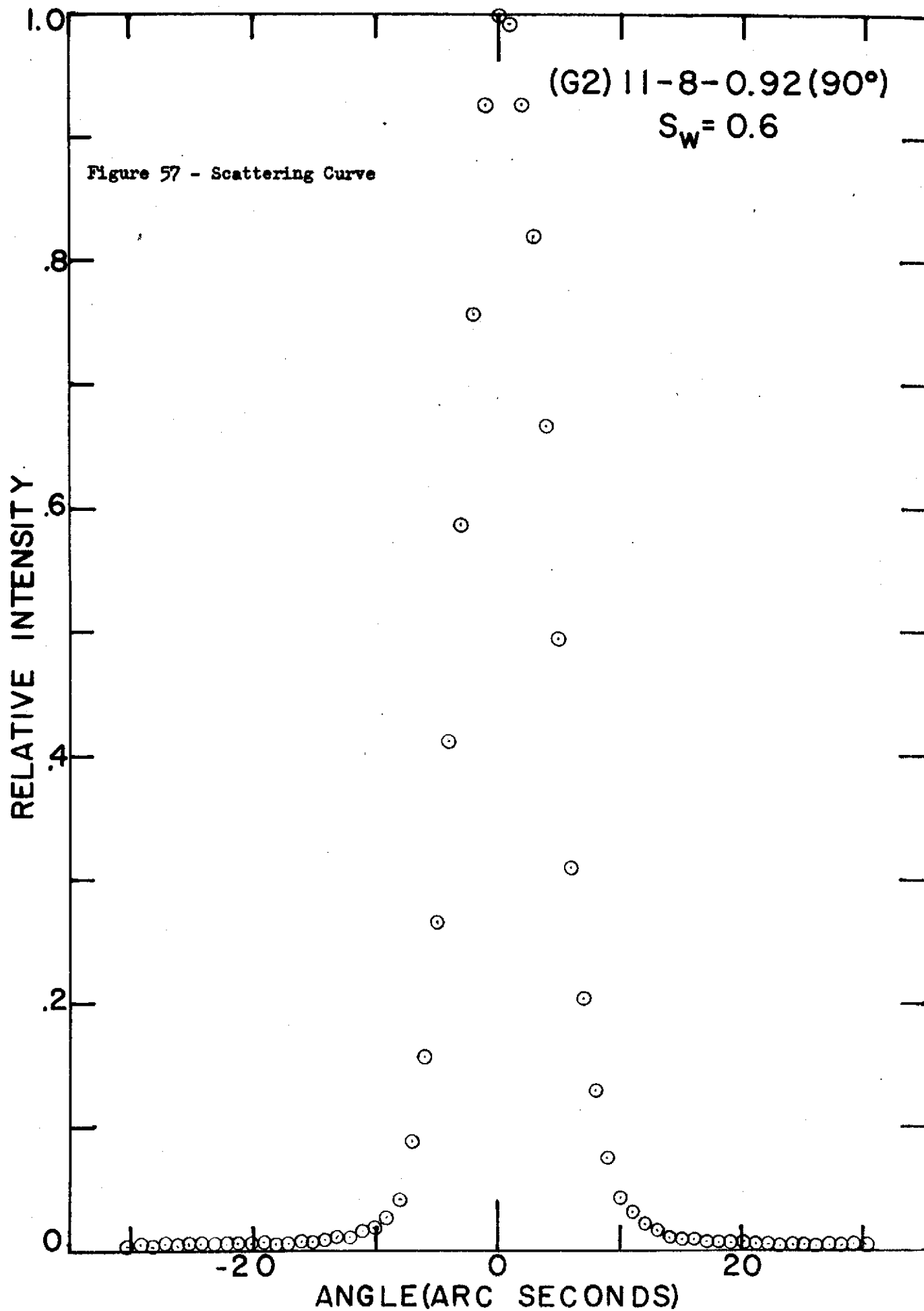


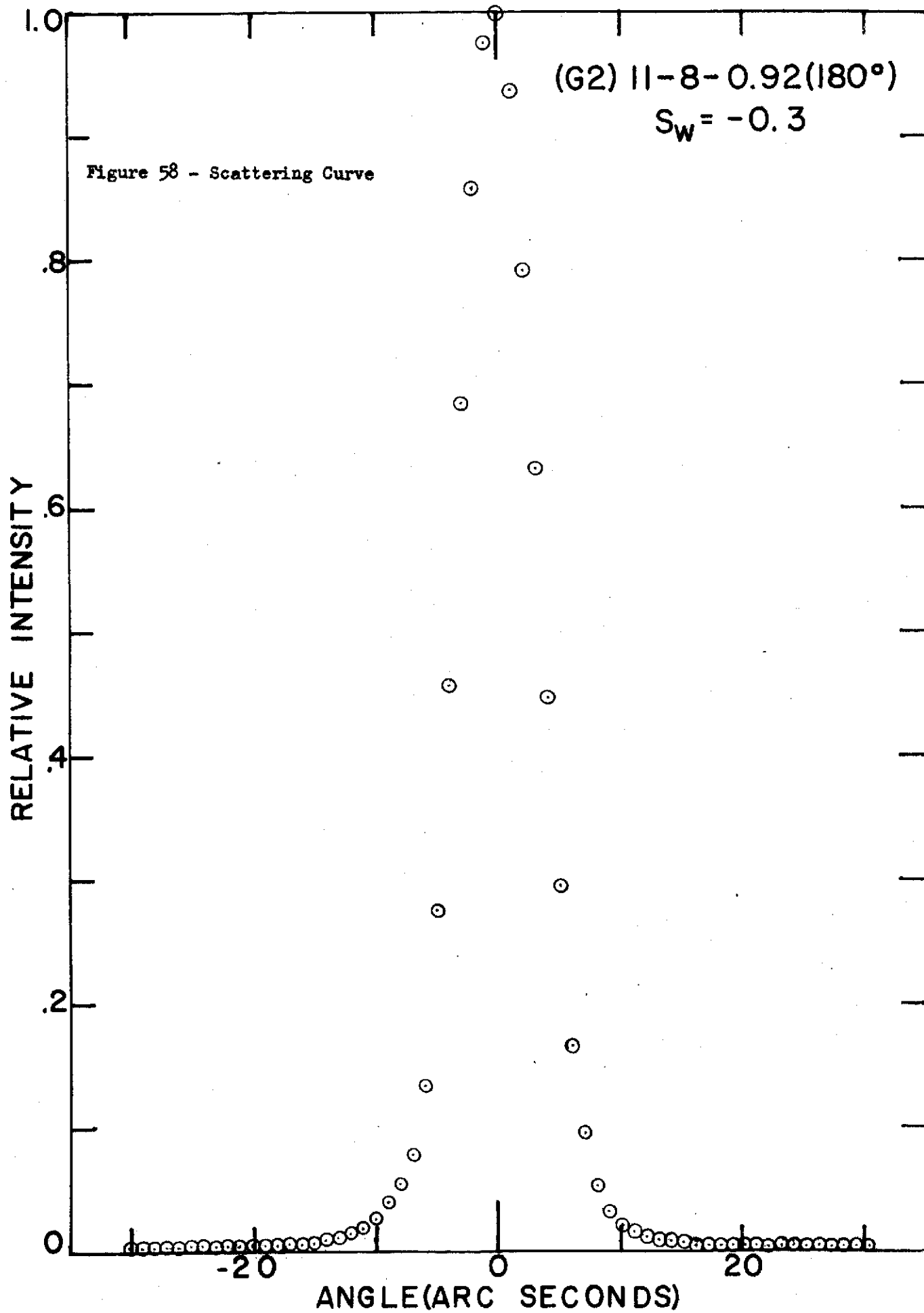












Angle (Arc Sec)		-30	-20	-10	-5	0	5	10	20	30
Sample No.	Rotation Angle (Deg)	Relative Intensity								
2	0	.001	.003	.018	.276	1.000	.233	.017	.005	.001
	45	.003	.005	.021	.322	1.000	.296	.032	.005	.003
	90	.003	.005	.038	.431	1.000	.261	.035	.005	.003
	180	.003	.005	.051	.358	1.000	.338	.023	.005	.003
7	0	.003	.006	.033	.331	1.000	.209	.023	.004	.003
	45	.003	.004	.031	.368	1.000	.215	.021	.005	.003
	90	.003	.005	.033	.372	1.000	.337	.031	.005	.003
	180	.003	.004	.024	.352	1.000	.331	.029	.004	.004
10	0	.006	.004	.030	.363	1.000	.473	.032	.004	.002
	45	.006	.007	.027	.213	1.000	.396	.026	.006	.004
	90	.005	.008	.040	.440	1.000	.406	.035	.007	.006
	180	.004	.006	.027	.302	1.000	.351	.035	.007	.005
11	0	.001	.004	.031	.402	1.000	.386	.031	.005	.001
	45	.003	.006	.053	.527	1.000	.265	.022	.006	.003
	90	.003	.006	.042	.494	1.000	.264	.019	.005	.003
	180	.003	.004	.021	.296	1.000	.277	.026	.003	.003

TABLE 8. Phase II Nine Point Data for Rotated Samples, $\lambda = 8.3 \text{ \AA}$,
0.92 Deg Incidence Angle

Sample No.	Rotation Angle (Deg)	Percent Scattered (S)	Scattering Width (S _w)	Efficiency Factor (E)
2	0	0.69	-0.6	0.01230
	45	0.97	-0.3	0.01056
	90	0.98	0.2	0.01086
	180	0.94	0.0	0.01063
7	0	1.0	-0.8	0.01938
	45	0.90	-0.8	0.00987
	90	0.88	-0.1	0.00958
	180	0.84	0.2	0.00774
10	0	0.83	0.4	0.01067
	45	1.39	-0.2	0.00726
	90	1.32	1.2	0.00714
	180	1.24	0.0	0.00743
11	0	0.64	0.6	0.01144
	45	0.91	0.7	0.00887
	90	0.96	0.6	0.00850
	180	0.79	-0.3	0.01004

TABLE 9. Phase II Test Results of Rotated Samples, $\lambda = 8.3 \text{ \AA}$,
0.92 Deg Incidence Angle

SAMPLES USED IN MEASUREMENTS

Four government-furnished samples were selected for Phase II of the program. These were numbered as follows:

<u>Sample No.</u>	<u>Material</u>	<u>Polishing Process</u>
2	CER-VIT	Fresh Feed
7	ULE	Ionic Bombardment
10	Aluminum with Polished Electroless Nickel Coating	Fresh Feed
11	Optical Grade Quartz	Bowl Feed

All samples appeared to have a good polished surface and did not show any irregularities on the surface.

SAMPLE MEASUREMENT SEQUENCE

The data for the Phase II program was taken as follows:

A. Align system for 0.5° angle of incidence and 0° orientation of samples.

	Sample No.	Source (Wavelength)
A1.	2.	$13.3 \overset{\circ}{\text{A}}$
A2.	2	$8.34 \overset{\circ}{\text{A}}$
A3.	7	$8.34 \overset{\circ}{\text{A}}$
A4.	7	$13.3 \overset{\circ}{\text{A}}$
A5.	10	$13.3 \overset{\circ}{\text{A}}$
A6.	10	$8.34 \overset{\circ}{\text{A}}$
A7.	11	$8.34 \overset{\circ}{\text{A}}$
A8.	11	$13.3 \overset{\circ}{\text{A}}$

B. Align system for 0.92° angle of incidence and 0° orientation of samples.

	Sample No.	Source (Wavelength)
B1.	11	13.3 Å
B2.	11	44 Å
B3.	10	44 Å
B4.	10	13.3 Å
B5.	7	13.3 Å
B6.	7	44 Å
B7.	2	44 Å
B8.	2	13.3 Å

C. Align system for 1.5° angle of incidence and 0° orientation of samples.

	Sample No.	Source (Wavelength)
C1.	2	13.3 Å
C2.	2	44 Å
C3.	2	8.34 Å
C4.	7	8.34 Å
C5.	7	44 Å
C6.	7	13.3 Å
C7.	10	13.3 Å
C8.	10	44 Å
C9.	10	8.34 Å
C10.	11	8.34 Å
C11.	11	44 Å
C12.	11	13.3 Å

D. Align system for 2.0° angle of incidence and 0° orientation of samples.

	Sample No.	Source (Wavelength)
D1.	11	13.3 Å
D2.	11	44 Å
D3.	11	8.34 Å
D4.	10	8.34 Å
D5.	10	44 Å
D6.	10	13.3 Å
D7.	7	13.3 Å
D8.	7	44 Å
D9.	7	8.34 Å
D10.	2	8.34 Å
D11.	2	44 Å
D12.	2	13.3 Å

E. Align system for 4.0° angle of incidence and 0° orientation of samples.

	Sample No.	Source (Wavelength)
E1.	2	44 Å
E2.	7	44 Å
E3.	10	44 Å
E4.	11	44 Å

F. Align system for 0.92° angle of incidence and with 8.34 \AA source.

	Sample No.	Orientation (Degrees)
F1.	11	180
F2.	11	90
F3.	11	45
F4.	10	180
F5.	10	90
F6.	10	45
F7.	7	180
F8.	7	90
F9.	7	45
F10.	2	180
F11.	2	90
F12.	2	45

CONCLUSIONS

There are some general trends shown by the data they are:

1. The percent scattering of x-rays was greater at 44 \AA than 13.3 \AA and 8.3 \AA for the four samples.
2. Performance of the metal sample (#10) showed a larger magnitude of scattering at 8.3 and 13.3 \AA but compares favorably at 44 \AA with those of the glass surfaces.
3. The orientation tests showed that 3 of the 4 samples increased in scattering as a function of angular position from 0° . Sample #7 showed a decrease in scattering for this test.
4. The two samples that generally showed the least amount of scattering were samples #7 and #11.

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